Climate- and Human-Induced Vegetation Changes in Northwestern Turkey and the Southern Levant since the Last Glacial

Dissertation

zur Erlangung des Doktorgrades (Dr. rer. nat.)

der Mathematisch-Naturwissenschaftlichen Fakultät

der Rheinischen Friedrich-Wilhelms-Universität Bonn

vorgelegt von

Andrea Miebach

aus Bergisch Gladbach

Bonn, 2016

Angefertigt mit Genehmigung der Mathematisch Naturwissenschaftlichen Fakultät
der Rheinischen Friedrich-Wilhelms-Universität Bonn

1. Gutachter:	Prof. Dr. Thomas Litt
2. Gutachter:	Prof. Dr. Dietmar Quandt
Tag der Promotion:	27.01.2017
Erscheinungsjahr:	2017

Contents

1 General Introduction

2 Impacts of climate and humans on the vegetation in northwestern Turkey: palynological insights from Lake Iznik since the Last Glacial

5 Synthesis

Summary

Northwestern Turkey and the southern Levant are key regions for studying vegetation and climate developments during migration phases of modern humans and the origin and expansion of agriculture. Both regions have a long history of different anthropogenic occupation phases, and the vegetation was sensitive to climate variations and anthropogenic influences. However, paleoenvironmental conditions in northwestern Turkey and the southern Levant are still insufficiently understood. Therefore, the main aim of this doctoral thesis was to investigate climate- and human-induced vegetation changes in both regions during the Last Glacial and Holocene.

To fulfill this aim, palynological studies at three lacustrine archives were conducted. Pollen, non-pollen palynomorphs such as green algae and spores, and microscopic charcoal were extracted from sediment cores and microscopically analyzed. The sediment cores originated from Lake Iznik (northwestern Turkey), the Sea of Galilee (Lake Kinneret), and the Dead Sea (both southern Levant).

Pollen data inferred from Lake Iznik sediments reveal the vegetation pattern in northwestern Turkey during the past 31 ka BP (thousand years before present). The vegetation changed between (a) steppe during stadials suggesting dry and cold climatic conditions, (b) forest-steppe during interstadials implying milder and more humid climatic conditions, and (c) oak-dominated mesic forest during the Holocene indicating warm and humid climatic conditions. A distinct succession of pioneer trees, cold temperate trees, warm temperate trees, and Mediterranean trees occurred since the Lateglacial. Rapid climate changes reflected in vegetation shifts correlate with Dansgaard-Oeschger events (DO-4, DO-3, and DO-1), the Younger Dryas, and most likely the 8.2 ka event. The distinction between climate- and human-induced vegetation changes is challenging during early settlement phases. Nevertheless, evidence for human activity consolidates since ca. 4.8 ka BP (Early Bronze Age). Forests were cleared, and cultivated trees, crops, and secondary human indicator taxa appeared. Subsequent fluctuations between extensive agricultural uses and regenerations of the natural vegetation occurred.

The palynological investigation at the Dead Sea provides insights into the vegetation history of the southern Levant between ca. 88 and 9 ka BP. The pollen record from the Sea of Galilee yields additional information for 28–22 ka BP, when the Sea of Galilee rose above the modern lake level and temporarily merged with Lake Lisan, the Last Glacial precursor of the Dead Sea. A mixture of Irano-Turanian steppe communities, Saharo-Arabian desert vegetation, and Mediterranean woodland components occurred in the Dead Sea region during the Last Glacial. Pollen proportions of these three biomes changed over time mainly in response to changes in effective moisture (available moisture for plants). During the early Last Glacial (marine isotope stage (MIS) 5b/a and early MIS 4), the amount of Saharo-Arabian desert components was higher relative to later phases indicating low effective moisture. An increased proportion of Irano-Turanian steppe vegetation and Mediterranean woodland elements during the late MIS 4, MIS 3, and MIS 2 suggest more effective moisture. MIS 2 was the coldest period of the investigated timeframe as indicated by a change in arboreal taxa. An assessment of the vegetation and climate gradients in the southern Levant during MIS 2 is possible by comparing the Sea of Galilee and Dead Sea pollen datasets. The well-dated and high-resolution pollen record from the Sea of Galilee suggests that steppe vegetation with dwarf shrubs, grasses, and other herbs predominated in northern Israel during 28–22 ka BP. In contrast to the Holocene, dense Mediterranean woodland did not cover the surroundings of the Sea of Galilee. Thermophilous trees were probably patchily distributed in the whole study area. The gradient of effective moisture between the Sea of Galilee and the Dead Sea/Lake Lisan was not as strong as today. The Dead Sea region witnessed several environmental changes during the Lateglacial and early Holocene caused by climatic variations and/or anthropogenic influences. After these rapid and pronounced changes, a considerably different ecosystem with sparse Mediterranean woodland, high fire activity, and strong catchment erosion prevailed in the Dead Sea region.

While the results for northwestern Turkey are largely in line with previous regional vegetation and climate studies, previous investigations from the southern Levant concluded contrasting environmental scenarios for the Last Glacial and early Holocene. Thus, the new palynological results for the southern Levant apparently contradict some of the previous hypotheses. Therefore, factors influencing the pollen assemblage and the plant cover are discussed.

The three palynological investigations provide insights into long-term and short-term variations of the paleoenvironment in northwestern Turkey and the southern Levant since the Last Glacial. They contribute to our understanding of interactions between vegetation, climate, and humans in the Eastern Mediterranean. This knowledge is not only essential for reconstructing the migration history of modern humankind but also helps to evaluate effects of current and future climate changes on the environment.

1 General Introduction

1.1 Background

This doctoral thesis is affiliated to the Collaborative Research Centre (CRC) 806 “Our way to Europe” funded by the German Research Foundation. The CRC 806 investigates the interaction between past environmental conditions (e.g., climate and vegetation), cultural changes, and the mobility of anatomically modern humans (*Homo sapiens sapiens*). It uses an interdisciplinary approach combining archaeology and geosciences to capture the complexity of various research fields, methods, and concepts. The CRC 806 concerns the last 190 ka BP (kilo years before present; all radiocarbon dates in this chapter have been calibrated), the interval between the dispersal of modern humans from East Africa and the permanent establishment of *Homo sapiens sapiens* in Central Europe. It focuses not only on the primary expansion of modern humans towards Europe but also on secondary expansions and retreats of modern man along the dispersal corridors. The CRC 806 covers various projects grouped in clusters with different spatial focuses: A) the source region in East Africa, B) the eastern trajectory via the Near East and the Balkans, C) the western trajectory via North Africa and the Iberian Peninsula, and D) the sink region in Central Europe (Richter et al., 2012b).

The western trajectory is a possible corridor. Investigations try to answer whether the strait of Gibraltar was a barrier or bridge between North Africa and the Iberian Peninsula for human dispersal. In contrast, the eastern trajectory (cluster B) was the principal corridor of human dispersal (Richter et al., 2012b). Major dispersal events took place at the eastern trajectory. Firstly, the initial dispersal of *Homo sapiens sapiens* out of Africa. The earliest representatives of modern humans outside Africa are skeletons from the Israeli cave sites Qafzeh and Skhul, which were dated to 120–90 ka BP (Richter et al., 2012a and references therein). Secondly, the reoccupation of the Near East during the Last Glacial. Earliest fossil evidence is provided by skeletal material from Manot Cave, Israel, dating back to ca. 55 ka BP (Hershkovitz et al., 2015). And thirdly, the spread of agriculture and husbandry from the Near East to Central Europe during the Holocene. Clear evidence of agriculture and domestication of several animals goes back to about 11 ka BP in the so-called Fertile Crescent (Miller, 1991; Shea, 2013). Still, only little is known about the detailed framework of environmental conditions during these important dispersal processes.

Project B3 of cluster B focuses on environmental responses to climate impacts in the southern Levant (geographical area in the southeastern Mediterranean region). The southern Levant is a key region for studying the relationship between cultural and environmental changes. It has a long archaeological record not only with fossils and artefacts of modern humans but also of Neanderthals (Shea, 2008 and references therein). The region is regarded as a possible meeting point where gene flow between early modern humans and Neanderthals could have occurred (Kuhlwilm et al., 2016). Today, the southern Levant is a transitional area of different climate and vegetation zones: subhumid Mediterranean woodland, semiarid steppe, and arid desert (Zohary, 1962). The occurrence of different vegetation types within a small region makes the southern Levant a sensitive region for reconstructing climate changes in the past. The Dead Sea is a key archive for investigating the 220 ka old history of climate and vegetation change in the southern Levant (Neugebauer et al., 2014; see chapter 4). Together with a sediment profile from the nearby Sea of Galilee (Hazan et al., 2005), the detection of environmental gradients is possible (see chapter 3 and 4).

Project B4 of cluster B concerns the climatic evolution of the Marmara Region during the past 50 ka. The Marmara region, surrounding the Marmara Sea in northwestern Turkey, is situated at an important bottleneck for human migration. Of particular interest are the following intervals: firstly, the Lateglacial when human habitats reestablished after the Last Glacial Maximum (LGM) and secondly, the early and middle Holocene when farming and husbandry dispersed from the Near East to Central Europe (Richter et al., 2012b). A key archive for investigating the regional environmental development is Lake Iznik, the largest lake in the Marmara region. Its sedimentological, geochemical, and biological (e.g., pollen) composition enables the reconstruction of the paleolimnology, paleovegetation, and paleoclimate of the past 31 ka (Roeser et al., 2012, 2016; Ülgen et al., 2012; see chapter 2).

The investigation of the paleoenvironment, particularly the vegetation and climate, in the Eastern Mediterranean is not only substantial to understand the history of humankind but also to evaluate climate changes in the past. Understanding the nature of climate variations in the past and its influences on the environment is crucial to predict impacts of recent and future climate changes. While instrumental and historical climate records are only available for the last few centuries, paleoclimatic proxy data are necessary to understand Earth system feedbacks and climate variations on a longer timescale (Schönwiese, 2008; Masson-Delmotte et al., 2013). According to the latest Intergovernmental Panel on Climate Change Assessment Report (IPCC, 2013), concentrations of greenhouse gases have excessively increased, the Earth’s surface temperature has unprecedentedly became warmer, and the sea level has risen during the last decades. Moreover, precipitation rates in the Eastern Mediterranean have decreased. With the help of climate models, implications of recent and future climate changes can be predicted. Even under different scenarios of anthropogenic forcings, climate models predict a further rise in temperature and a further decrease in precipitation in the Eastern Mediterranean until the end of the 21st century.

To reveal the vegetation and climate history, palynology is a powerful technique. Palynology is the study of pollen and other microscopic organic-walled particles, so called non-pollen palynomorphs (NPPs), such as spores and algae. Seed plants produce pollen grains (male microgametophytes) in great abundance for reproduction. Pollen grains are usually dispersed by wind, water, or animals to pollinate other plants (Faegri and Iversen, 1989). However, particularly wind-transported pollen grains often do not reach the plants but deposit in the landscape. Lakes are natural pollen traps in terrestrial environments. They receive water and sediments from the catchment area, which usually also contain pollen grains. Other pollen grains directly reach the water surface or are produced by local aquatic plants growing in the water. Pollen grains and other sediment components deposit successively on the lake bottom (Moore et al., 1991). Pollen grains have a resistant coat (exine) made of sporopollenin. Under appropriate conditions, the exine can be preserved up to millions of years (Straka, 1975).

Nowadays, lacustrine sediments can be recovered by drilling. Sediment profiles are correlated in time with the help of dating techniques and age-depth models. Sediment samples from drilling cores are processed in laboratories to extract palynomorphs from the sediment. Pollen grains, which are specific to plant families, genera, or even species, and NPPs can be microscopically identified. By counting a statistically robust number of pollen and NPP types per sample along the sediment profile, developments in the environment, particularly the vegetation, can be reconstructed. However, the proportion of each pollen type depends not only on the number of parent plants but also on their pollen productivity, pollen transport, and preservation conditions. Hence, the counted pollen assemblage is an indirect record of the local and regional vegetation and needs to be interpreted. Nevertheless, pollen and NPPs provide valuable information about the history of the lake, the surrounding vegetation, and possible human impacts on the paleoenvironment (Faegri and Iversen, 1989; Moore et al., 1991). Pollen data can also be used to reconstruct the regional climate history because the occurrence and frequency of plants strongly correlate with the regional climate (Birks et al., 2010). In contrast to macrofossil remains, pollen grains are produced in high amounts and are widely spread. This provides the opportunity not only for qualitative but also quantitative vegetation and climate reconstructions (Faegri and Iversen, 1989). The processed sediment samples often additionally contain microscopic charcoal, which can be used to reconstruct fire regimes in the past (Whitlock and Larsen, 2001).

1.2 Current state of knowledge

Several global and northern hemispheric climate changes affected the Eastern Mediterranean region during the Quaternary. These climate changes were of long-term or short-term kind. Long-term climate variations were triggered by calculable orbital parameters affecting the insolation on the Earth (Fig. 1.1c) and resulting in the so-called Milankovitch cycles (Hays et al., 1976; Berger, 1978). Those climatic cycles composed of cold stages (glacials) and warm stages (interglacials). Each glacial-interglacial cycle of the late Quaternary encompassed averagely 100 ka (Lowe and Walker, 2015). Imprints of long-term climate changes are for example represented by marine isotope stages (MIS), which can be derived from oxygen isotope ($\delta^{18}O$) records of benthic foraminifera. Changes in benthic $\delta^{18}O$ were related to temperature, global ice volume, and water salinity (Lisiecki and Raymo, 2005; Fig. 1.1a). MIS 1 corresponds to the current interglacial, the Holocene (Sanchez Goñi and Harrison, 2010). The Last Glacial has been either defined as the period corresponding to MIS 4–2 (Sanchez Goñi and Harrison, 2010) or MIS 5d–2 (Dansgaard et al., 1993; Litt, 2007).

Several rapid short-term climate changes occurred during the Last Glacial. Interstadials were warm phases within a glacial that were either too short or cold to reach the climatic conditions of an interglacial (Jessen and Milthers, 1928). Interstadials are also described as Dansgaard-Oeschger (DO) events (Dansgaard et al., 1982; Rasmussen et al., 2014) and are associated with an abrupt warming followed by a gradual re-cooling. They are well documented in high-resolution Greenland ice core records (e.g., NGRIP members, 2004; Fig. 1.1b). 25 DO events occurred during the Last Glacial (MIS 5d–2). Their duration varied from centuries to several millennia (Rasmussen et al., 2014). Stadials were cold phases within a glacial. One of the coldest phases was the Last Glacial Maximum (LGM) when global ice volume maximized at 23–19 ka BP (Mix et al., 2001). Other very pronounced cold phases are associated with Heinrich events when ice-rafted debris deposited in the North Atlantic caused by massive discharges of icebergs (Heinrich, 1988; Bond et al., 1992; Fig. 1.1b: H1–H10). Subsequently, the Atlantic thermohaline circulation broke down (Broecker and Hemming, 2001; Rahmstorf, 2002). Climatic imprints related to Heinrich events are documented in many northern hemispheric records (e.g., Hemming, 2004; Robinson et al., 2006).

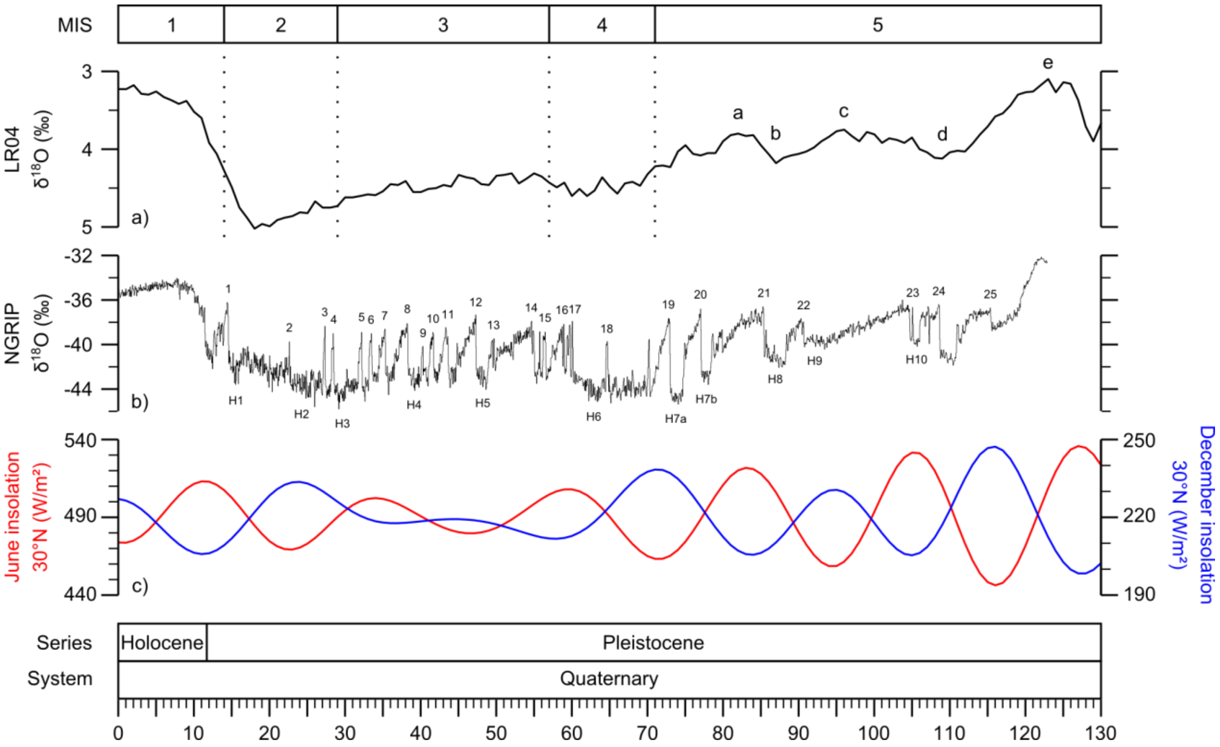


Figure 1.1: Paleoclimate records: a) LR04 benthic $\delta^{18}O$ stack and derived marine isotope stages (MIS; Lisiecki and Raymo, 2005); b) Greenland $\delta^{18}O$ record (NGRIP members, 2004) with numbered Dansgaard-Oeschger events (above; Rasmussen et al., 2014) and Heinrich events (below; Rasmussen et al., 2003); c) Summer and winter insolation for the 30th parallel north (Berger and Loutre, 1991).

Insights into the local and regional paleoenvironmental conditions of the Eastern Mediterranean have been gained by various investigations of different disciplines. Among these investigations were for instance lake level reconstructions (e.g., Bartov et al., 2003), climate reconstructions based on tree rings (e.g., Touchan et al., 2007), geochemical investigations of loess deposits (e.g., Obreht et al., 2015), and marine isotope records (e.g., Cheddadi and Rossignol-Strick, 1995; Almogi-Labin et al., 2009). Different methods were used to reveal the local or regional paleovegetation of the Eastern Mediterranean including macrofossil analyses, i.e. the study of macroscopic plant remains such as seeds, fruits, and leaves (e.g., Marinova and Atanassova, 2006), phytolith analyses, i.e. the study of siliceous plant remains (e.g., Turner et al., 2010), and carbon isotope ($\delta^{13}C$) analyses of speleothems (e.g., Frumkin et al., 2000; Vaks et al., 2006). Measurements of $\delta^{13}C$ mainly mirror the ratio of C_3 plants to arid-adapted C_4 plants as well as the vegetation density overlying the cave. But $\delta^{13}C$ can also be influenced by other factors (Bar-Matthews et al., 1997; Frumkin et al., 2000). The most common method to study the paleovegetation of the Eastern Mediterranean is the pollen analysis. The study of fossil pollen is the only quantitative method that provides a continuous and adequate representation of vegetation changes in the past (Faegri and Iversen, 1989; Moore et al., 1991; Sadori et al., 2016). In addition to pollen, palynological analyses provide microscopic charcoal and NPPs such as dinoflagellates and green algae, which supported the reconstruction of paleoenvironmental conditions of the Eastern Mediterranean in previous studies (e.g., Shumilovskikh et al., 2014; Pickarski et al., 2015).

Previous palynological studies from the Eastern Mediterranean and Near East documented long-term vegetation changes in response to glacial-interglacial cycles. The majority of these investigations agreed on variations between forest expansion during interglacials and a dominance of open, steppic vegetation during glacials. However, strong spatial differences in vegetation density and plant composition prevailed (e.g., Tzedakis et al., 2006; Litt et al., 2014; Sadori et al., 2016). Moreover, many pollen records mirror vegetation changes in response to short-term climate oscillations. DO events, i.e. rapid warming events, were frequently identified in pollen studies from the northeastern Mediterranean and Near East. Those investigations indicated a spread of woody taxa, although woodland intensities differed from region to region (e.g., Fletcher et al., 2010; Müller et al., 2011; Panagiotopoulos et al., 2014; Pickarski et al., 2015). The effect of DO events on the vegetation in the Levant is less clear. This might be partly caused by a low data resolution or chronological uncertainties (cf. Niklewski and Van Zeist, 1970; Cheddadi and Rossignol-Strick, 1995). Most pollen records from the Eastern Mediterranean and Near East do not indicate a clear vegetation response related to Heinrich events, i.e. harsh stadial conditions (e.g., Tzedakis et al., 2004; Shumilovskikh et al., 2014). In areas where tree populations were already close to their climatic tolerance limit, differences between pronounced Heinrich Stadials and other stadials might not be recorded. Even moderate stadial conditions could have crossed the ecological threshold for tree growth (Tzedakis et al., 2004). However, Langgut et al. (2011) suggested distinct vegetation responses associated with Heinrich events inferred from a marine pollen record from the Levantine Basin.

Fig. 1.2 shows the location of long marine and lacustrine pollen records in the Eastern Mediterranean and Near East. The largest density of long pollen records occurs on the Balkan Peninsula. Here, the longest continuous pollen record from the Eastern Mediterranean, namely the pollen record from Tenaghi Philippon, Greece, spanning 1.35 million years, has been obtained (e.g., Tzedakis et al., 2006). Other palynological studies that reach further back in time than the Last Glacial took place at Lake Ohrid (Macedonia/Albania, 500 ka, e.g. Sadori et al., 2016), Lake Prespa (Macedonia/Albania/Greece, 92 ka, e.g. Panagiotopoulos et al., 2014), Ioannina (Greece, 130 ka, e.g. Tzedakis et al., 2002), and Kopais (Greece, 130 ka, e.g. Tzedakis, 1999). Investigations of the vegetation history at the Greek sites of Xinias and Megali Limni encompassed major parts of the Last Glacial and Holocene (e.g., Digerfeldt et al., 2000; Margari et al., 2009). Marine cores from Marmara Sea and Black Sea provided records for the last 34 and 64 ka, respectively (Mudie et al., 2002; Shumilovskikh et al., 2012, 2014; Valsecchi et al., 2012). Marine and terrestrial vegetation studies differ from each other. Firstly, marine records usually represent a very large vegetation signal because the pollen source area is positively related to the archive size (Jacobson and Bradshaw, 1981). And secondly, pine pollen are usually greatly overrepresented in marine sediments (Faegri and Iversen, 1989). However, long terrestrial pollen records from Anatolia were almost lacking. The only previous long pollen record originated from Lake Van in Eastern Anatolia (E Turkey, 600 ka, e.g. Litt et al., 2014). In its vicinity, two additional terrestrial archives that were used for paleovegetational studies exist: Lake Urmia (NW Iran, 200 ka, e.g. Djamali et al., 2008) and Lake Zeribar (W Iran, 45 ka, e.g. van Zeist and Bottema, 1977).

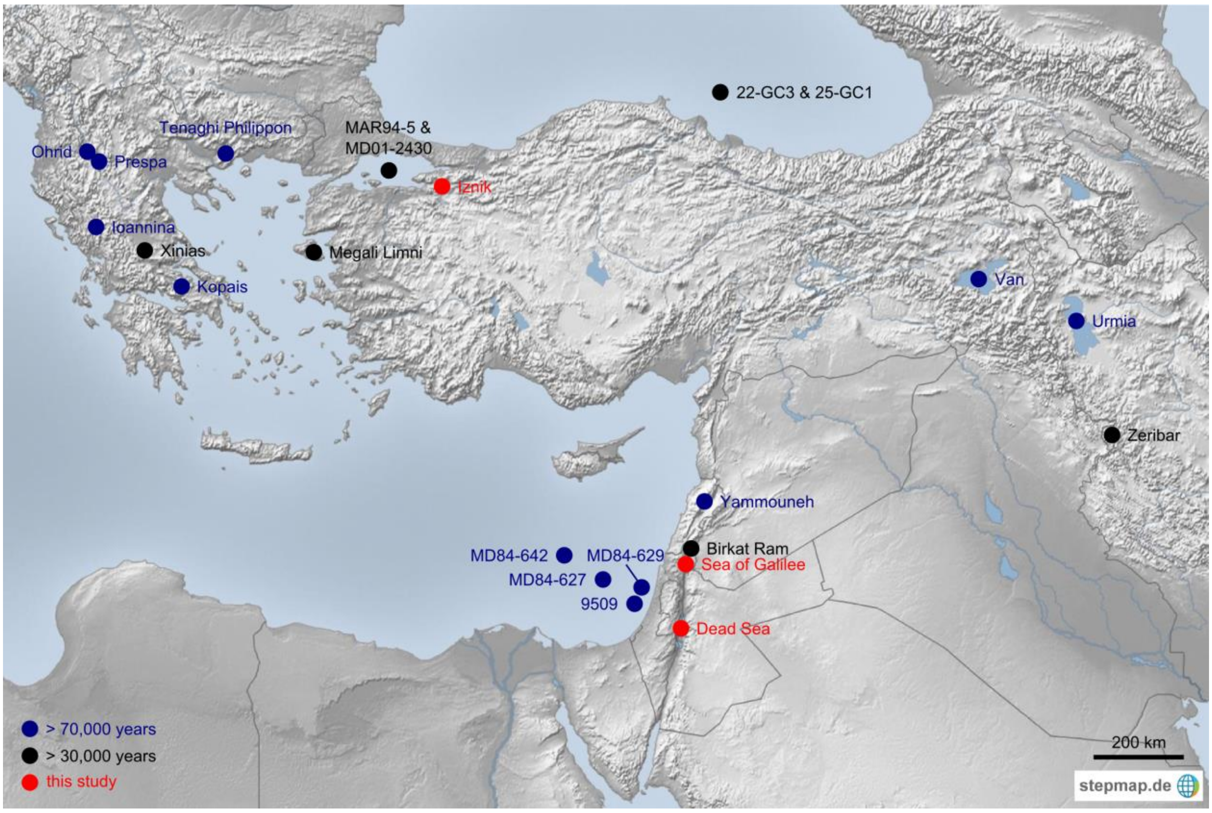


Figure 1.2: Location of long pollen records in the Eastern Mediterranean/Near East (with adequate chronologies and resolution). Blue: previous pollen records encompassing at least the last 70 ka (MIS 4–1). Black: previous pollen records encompassing at least the last 30 ka (MIS 2–1). Red: pollen records of this study.

Several palynological studies took place in the Levant. Four marine cores from the Levantine Basin are available and encompass the past 70 to 250 ka. They represent a huge pollen source area due to the basin size, and they were influenced by pollen brought by the Nile, particularly during glacial periods when the sea level was lower (Cheddadi and Rossignol-Strick, 1995; Langgut et al., 2011). Various terrestrial paleovegetational studies took place in the Levant during the 1960s to 1990s. According to these studies, several pollen records encompass partly or completely the Last Glacial and Holocene (e.g., Ghab Valley, Niklewski and Van Zeist, 1970; Sea of Galilee, Horowitz, 1971; Birkat Ram, Weinstein, 1976; Dead Sea, Horowitz, 1979; Hula Basin, Weinstein-Evron, 1983). Based on available pollen data, Horowitz (1992) presented a vegetation model for northern Israel and the Dead Sea region. This model suggests a predominance of Mediterranean forests in northern Israel during the Last Glacial (MIS 4–2) and a considerable reduction of Mediterranean forests and spread of steppe during interglacials (MIS 5 and 1). For the Dead Sea region, the model suggests a spread of Mediterranean woodland during MIS 4 and 2, and the occurrence of steppe and desert vegetation during MIS 5, 3, and 1. These hypotheses were in line with climatic interpretations of other investigations such as lake level reconstructions, but they contrasted pollen studies from other parts of the Eastern Mediterranean. However, the sedimentary sequences used for pollen analyses in the southern Levant were mostly sparsely dated and following studies questioned some chronologies (e.g., Rossignol-Strick, 1995; van Zeist et al., 2009). In addition, those previous pollen records were often of low resolution, or pollen counts were statistically not reliable. Subsequent long terrestrial Levantine pollen records have been obtained from Yammouneh

(Lebanon, 400 ka, e.g. Gasse et al., 2015) and Birkat Ram (N Israel, 30 ka, e.g. Schiebel, 2013). They are chronologically better constrained and of higher resolution. Both pollen records suggest contrasting vegetation developments, namely the predominance of Mediterranean forests during interglacials and the occurrence of steppe vegetation during glacials. However, during glacial periods, these sites were probably influenced by orographic effects given the high altitudes (cf. Develle et al., 2011). The vegetation at lower altitudes might have differed considerably.

During the Holocene, the Eastern Mediterranean environment was more and more influenced by anthropogenic impacts. On the one hand, this made it more difficult to clearly ascribe vegetation changes identified in pollen records to climate variations, particularly during the late Holocene (e.g., Roberts, 1990; Wick et al., 2003). On the other hand, it allowed to study influences of humans on the ecosystem and enabled the comparison of palynological investigations to archaeological records (e.g., Bottema et al., 2001; Shumilovskikh et al., 2016). Signs of cereal cropping, fruticulture, grazing, and forest clearance were traced in palynological assemblages (e.g., Behre, 1990; Bottema and Woldring, 1990). In addition, secondary impacts of human activities such as increased erosion rates and altered fire regimes were identified (e.g., Eastwood et al., 1998; Quintana Krupinski et al., 2013). However, some difficulties to record prehistoric occupation phases in pollen records from the Near East compared to other regions, e.g. Central Europe, were described. Firstly, most cultivated species such as cereals and olive trees already occurred naturally in the Near East. Secondly, several secondary indicator species (non-cultivated plants that benefit from anthropogenic influences) were also common in the Near East before humans started to change their environments. And thirdly, the sensitivity of the vegetation to minor climate variations made a separation between anthropogenic and climatic influences difficult (Behre, 1990; Bottema and Woldring, 1990).

The timing and kind of human-induced alterations of the ecosystem depend on the regional and local settlement history. The southern Levant has a long archaeological record of different settlement phases. Sedentism occurred already during the Last Glacial by Natufian people (Bar-Yosef, 1998) but anthropogenic activities amplified during the early Holocene. Plants such as cereals and pulses were cultivated and agriculture spread. Neolithic settlers domesticated animals such as sheep and goat and used them for pastoral farming. The regional population grew and sedentary village life emerged (Kuijt and Goring-Morris, 2002; Shea, 2013). By the ninth millennium BP, Neolithic farming communities reached northwestern Turkey (Özdoğan, 2011; Düring, 2013). Several important prehistoric settlements are situated near Lake Iznik, namely Ilıpınar, Hacılar tepe, Menteşe, and Barcın Höyük (Roodenberg and Roodenberg, 2008; Roodenberg et al., 2008). They provided insights into local settlement structures and the Neolithic way of life in the eastern Marmara region.

1.3 Aim and structure of this thesis

Previous pollen records from the Eastern Mediterranean and Near East showed the sensitivity of the vegetation to respond to long-term and rapid climate oscillations in the past. However, several differences between records occurred concerning (a) the registration of individual oscillations, (b) the magnitude of vegetation and climate changes, (c) the nature of vegetation and climate variations mirrored for instance in the vegetation composition, and (d) the length of recorded events (Fletcher et al., 2010; Sanchez Goñi and Harrison, 2010, see also section 1.2). Long Eastern Mediterranean pollen records with adequate chronologies and resolution that encompass the Last Glacial and Holocene are rare (Fig. 1.2). The lack of available data is particularly unfavorable in key regions of human history such as the Marmara region in northwestern Turkey and the southern Levant. The vegetation history in both regions is not sufficiently understood. Therefore, high-resolution pollen records with robust and independent chronologies are needed to reveal environmental conditions in the past.

To gain new insights into the vegetation history in relation to climate changes and anthropogenic influences of northwestern Turkey and the southern Levant since the Last Glacial, pollen spectra of lacustrine archives were investigated. This doctoral thesis presents these palynological investigations and aims to address the following objectives:

I) Kind and magnitude of long-term environmental changes:
The interpretation of pollen assemblages allows to reconstruct the paleovegetation and paleoclimate. NPP and microscopic charcoal data yield additional information about environmental conditions in the past. Palynology does not only help to understand the kind of changes, but as a quantitative method it also provides insights into the magnitude of changes (Faegri and Iversen, 1989; Moore et al., 1991; Whitlock and Larsen, 2001).

II) Detection of rapid vegetation and climate changes:
If the vegetation is sensitive enough, it responds to short-term and minor climate variations. Well-dated sediment sequences and high-resolution analyses give the opportunity to detect not only long-term variations but also rapid changes.

III) Regional vegetation and climate gradients:
By comparing pollen records between each other and with other paleovegetation and paleoclimate studies, the detection of regional vegetation and climate gradients is possible. Special emphasis is given to environmental gradients between the Sea of Galilee and Dead Sea.

IV) Detection and timing of human influences on the vegetation:
Since the neolithization (begin of agriculture, husbandry, and sedentary village life), human influences on their environment grew (Miller, 1991; Rollefson and Köhler-Rollefson, 1992). It is possible to detect anthropogenic influences in pollen and NPP profiles (Bottema and Woldring, 1990). The comparison with archaeological findings helps to distinguish between human- and climate-induced vegetation changes.

To address these objectives, three lacustrine archives were selected for palynological investigations. These archives are particularly suitable because of the following criteria:

I) All of them are located on the eastern trajectory of modern human dispersal from East Africa to Europe. The Dead Sea and the Sea of Galilee are situated at the Dead Sea rift valley, a possible migration route of modern humans (Richter et al., 2012a). Lake Iznik is situated in the Marmara region, a bottleneck region for human migration between Anatolia and the Balkans (Richter et al., 2012b).

II) Important archaeological sites are in the vicinity of the lakes. The core from Sea of Galilee was directly drilled at the archaeological site of Ohalo II, which is a well-preserved Epipaleolithic fisher-hunter-gatherers site (Nadel et al., 1995). In addition, several archaeological sites are in Israel and Jordan, where remains of modern humans and Neanderthals are preserved (Shea, 2013).

Several Neolithic settlements are in close proximity of Lake Iznik, e.g. the well-investigated site of Ilıpınar (Roodenberg and Roodenberg, 2008). This gives the opportunity for direct comparisons of biogeological and archaeological records.

III) The lacustrine archives are located at climate and vegetation transition zones. The southern Levant is marked by a steep gradient in precipitation resulting in the transition between (a) subhumid Mediterranean woodland in the north, (b) semiarid Irano-Turanian steppe vegetation in the center, and (c) arid Saharo-Arabian desert vegetation in the south (Zohary, 1962). Lake Iznik borders two vegetation zones, which result from the transition of Mediterranean climate and Pontic climate: (a) Mediterranean woodland and (b) Euxinian mesic deciduous and mixed forest (Zohary, 1973). This makes the archives particularly sensitive for the detection of climate changes in the past. Already weak climate variations probably resulted in shifts of vegetation boundaries and alterations of pollen assemblages.

IV) The selected archives are the largest lakes of the regions of interest. They mainly represent a regional instead of a local pollen signal because the pollen source area is positively correlated to the archive size (Jacobson and Bradshaw, 1981). Thus, the reconstruction of the regional vegetation and climate is possible.

V) Site surveys and previous palynological studies demonstrated the suitability of the archives for vegetation analyses in response to climate changes and human impacts (e.g., Litt et al., 2012; Ülgen et al., 2012; Schiebel, 2013).

VI) However, previous palynological studies (with adequate chronologies and resolution) only encompassed parts of the Holocene. The timeframes of interest for the CRC 806 were not investigated yet.

This doctoral thesis describes three palynological studies based on lacustrine sediments of Lake Iznik, the Sea of Galilee, and the Dead Sea. The thesis provides new insights into the paleoenvironmental conditions in northwestern Turkey and the southern Levant since the Last Glacial. It reveals the paleovegetation in response to climate variations, human influences, and fire activity. In the future, the results can be used for quantitative climate analyses, predictions of recent and future climate changes, and evaluations of potential impacts on hominid population dynamics. The three palynological studies are presented in chapter 2–4. Each chapter gives an introduction by describing the specific background, previous investigations, and the aim of the study. Descriptions of each study area, the used material, the applied methods, and the results follow. The results are discussed with emphasis on temporal vegetation dynamics, their relation to short-term and long-term climate oscillations, and anthropogenic influences on the vegetation. The results are compared to other regional investigations such as pollen records, speleothem data, lake level reconstructions, and archaeological findings. Each chapter ends with a conclusion. Chapter 2 presents the palynological study of Lake Iznik. It is based on the following peer-reviewed publication:

Miebach, A.; Niestrath, P.; Roeser, P. & Litt, T. (2016): Impacts of climate and humans on the vegetation in northwestern Turkey: palynological insights from Lake Iznik since the Last Glacial. Climate of the Past 12: 575–593. Doi:10.5194/cp-12-575-2016.

The publication appears in this thesis in its original wording but with a slightly modified layout. Chapter 3 focuses on the palynological investigation at the Sea of Galilee. It is based on the following manuscript submitted for publication:

Miebach, A.; Chen, C.; Schwab, M. J.; Stein, M.; Litt, T. (2016): Vegetation and climate during the Last Glacial high stand (ca. 28–22 ka BP) of the Sea of Galilee, northern Israel. Quaternary Science Reviews: under review.

Chapter 4 deals with the palynological study of the Last Glacial and early Holocene Dead Sea entitled:

Last Glacial and early Holocene vegetation, climate, and fire history of the Dead Sea region inferred from palynological analyses.

It covers the timeframe between ca. 88 and 9 ka BP and connects to the Holocene pollen record published by Litt et al. (2012), which encompasses the last 10 ka BP. Chapter 4 will be submitted after performing some final analyses. Chapter 2–4 are conceptualized to allow an independent understanding. Chapter 5 is a synthesis of the three palynological studies. It addresses the four objectives of this doctoral thesis and summarizes the main conclusions of the three palynological investigations.

1.4 References

Almogi-Labin, A., Bar-Matthews, M., Shriki, D., Kolosovsky, E., Paterne, M., Schilman, B., Ayalon, A., Aizenshtat, Z., and Matthews, A.: Climatic variability during the last ∼90 ka of the southern and northern Levantine Basin as evident from marine records and speleothems, Quaternary Sci. Rev., 28, 2882–2896, doi:10.1016/j.quascirev.2009.07.017, 2009.

Bar-Matthews, M., Ayalon, A., and Kaufman, A.: Late Quaternary Paleoclimate in the Eastern Mediterranean Region from Stable Isotope Analysis of Speleothems at Soreq Cave, Israel, Quaternary Res., 47, 155–168, doi:10.1006/qres.1997.1883, 1997.

Bar-Yosef, O.: On the Nature of Transitions: the Middle to Upper Palaeolithic and the Neolithic Revolution, Camb. Archaeol. J., 8, 141–163, doi:10.1017/S0959774300001815, 1998.

Bartov, Y., Goldstein, S. L., Stein, M., and Enzel, Y.: Catastrophic arid episodes in the Eastern Mediterranean linked with the North Atlantic Heinrich events, Geology, 31, 439–442, doi:10.1130/0091-7613(2003)031<0439:Caeite>2.0.Co;2, 2003.

Behre, K.-E.: Some reflections on anthropogenic indicators and the record of prehistoric occupation phases in pollen diagrams from the Near East, in: Man's Role in the Shaping of the Eastern Mediterranean Landscape, edited by: Bottema, S., Entjes-Nieborg, G., and van Zeist, W., Balkema, Rotterdam, 219–230, 1990.

Berger, A.: Long-term variations of daily insolation and Quaternary climate changes, J. Atmos. Sci., 35, 2362–2367, doi:10.1175/1520-0469(1978)035<2362:LTVODI>2.0.CO;2, 1978.

Berger, A. and Loutre, M. F.: Insolation values for the climate of the last 10 million years, Quaternary Sci. Rev., 10, 297–317, doi:10.1016/0277-3791(91)90033-Q, 1991.

Birks, H. J. B., Heiri, O., Seppä, H., and Bjune, A. E.: Strengths and weaknesses of quantitative climate reconstructions based on late-Quaternary biological proxies, Open Ecol. J., 3, 68–110, doi:10.2174/1874213001003020068, 2010.

Bond, G., Heinrich, H., Broecker, W., Labeyrie, L., Mcmanus, J., Andrews, J., Huon, S., Jantschik, R., Clasen, S., Simet, C., Tedesco, K., Klas, M., Bonani, G., and Ivy, S.: Evidence for Massive Discharges of Icebergs into the North-Atlantic Ocean during the Last Glacial Period, Nature, 360, 245–249, doi:10.1038/360245a0, 1992.

Bottema, S. and Woldring, H.: Anthropogenic indicators in pollen diagrams of the Eastern Mediterranean, in: Man's Role in the Shaping of the Eastern Mediterranean Landscape, edited by: Bottema, S., Entjes-Nieborg, G., and van Zeist, W., Balkema, Rotterdam, 231–264, 1990.

Bottema, S., Woldring, H., and Kayan, I.: The Late Quarternary Vegetation History of Western Turkey, in: The Ilipinar Excavations II, edited by: Roodenberg, J. J. and Thissen, L. C., Nederlands Instituut voor het Nabije Oosten, Leiden, 327–354, 2001.

Broecker, W. S. and Hemming, S.: Climate Swings Come into Focus, Science, 294, 2308–2309, doi:10.1126/science.1068389, 2001.

Cheddadi, R. and Rossignol-Strick, M.: Eastern Mediterranean Quaternary paleoclimates from pollen and isotope records of marine cores in the Nile Cone Area, Paleoceanography, 10, 291–300, doi:10.1029/94PA02672, 1995.

Dansgaard, W., Clausen, H. B., Gundestrup, N., Hammer, C. U., Johnsen, S. F., Kristinsdottir, P. M., and Reeh, N.: A new Greenland deep ice core, Science, 218, 1273–1277, doi:10.1126/science.218.4579.1273, 1982.

Dansgaard, W., Johnsen, S. J., Clausen, H. B., Dahljensen, D., Gundestrup, N. S., Hammer, C. U., Hvidberg, C. S., Steffensen, J. P., Sveinbjornsdottir, A. E., Jouzel, J., and Bond, G.: Evidence for General Instability of Past Climate from a 250-Kyr Ice-Core Record, Nature, 364, 218–220, doi:10.1038/364218a0, 1993.

Develle, A. L., Gasse, F., Vidal, L., Williamson, D., Demory, F., Van Campo, E., Ghaleb, B., and Thouveny, N.: A 250 ka sedimentary record from a small karstic lake in the Northern Levant (Yammoûneh, Lebanon): Paleoclimatic implications, Palaeogeogr. Palaeocl., 305, 10–27, doi:10.1016/j.palaeo.2011.02.008, 2011.

Digerfeldt, G., Olsson, S., and Sandgren, P.: Reconstruction of lake-level changes in lake Xinias, central Greece, during the last 40 000 years, Palaeogeogr. Palaeocl., 158, 65–82, doi:10.1016/S0031-0182(00)00029-8, 2000.

Djamali, M., de Beaulieu, J.-L., Shah-hosseini, M., Andrieu-Ponel, V., Ponel, P., Amini, A., Akhani, H., Leroy, S. A. G., Stevens, L., Lahijani, H., and Brewer, S.: A late Pleistocene long pollen record from Lake Urmia, NW Iran, Quaternary Res., 69, 413–420, doi:10.1016/j.yqres.2008.03.004, 2008.

Düring, B. S.: Breaking the Bond: Investigating The Neolithic Expansion in Asia Minor in the Seventh Millennium BC, J. World Prehist., 26, 75–100, doi:10.1007/s10963-013-9065-6, 2013.

Eastwood, W. J., Roberts, N., and Lamb, H. F.: Palaeoecological and Archaeological Evidence for Human Occupance in Southwest Turkey: The Beyşehir Occupation Phase, Anatolian Studies, 48, 69–86, doi:10.2307/3643048, 1998.

Faegri, K. and Iversen, J.: Textbook of Pollen Analysis, 4 Edn., John Wiley &. Sons, Chichester, New York, Brisbane, Toronto, Singapore, 1989.

Fletcher, W. J., Sánchez Goñi, M. F., Allen, J. R. M., Cheddadi, R., Combourieu-Nebout, N., Huntley, B., Lawson, I., Londeix, L., Magri, D., Margari, V., Müller, U. C., Naughton, F., Novenko, E., Roucoux, K., and Tzedakis, P. C.: Millennial-scale variability during the last glacial in vegetation records from Europe, Quaternary Sci. Rev., 29, 2839–2864, doi:10.1016/j.jas.2011.05.007, 2010.

Frumkin, A., Ford, D. C., and Schwarcz, H. P.: Paleoclimate and vegetation of the last glacial cycles in Jerusalem from a speleothem record, Global Biogeochem. Cy., 14, 863–870, doi:10.1029/1999gb001245, 2000.

Gasse, F., Vidal, L., Van Campo, E., Demory, F., Develle, A.-L., Tachikawa, K., Elias, A., Bard, E., Garcia, M., Sonzogni, C., and Thouveny, N.: Hydroclimatic changes in northern Levant over the past 400,000 years, Quaternary Sci. Rev., 111, 1–8, doi:10.1016/j.quascirev.2014.12.019, 2015.

Hays, J. D., Imbrie, J., and Shackleton, N. J.: Variations of the Earth's Orbit: Pacemaker of the Ice Ages, Science, 194, 1121–1132, doi:10.1126/science.194.4270.1121, 1976.

Hazan, N., Stein, M., Agnon, A., Marco, S., Nadel, D., Negendank, J. F. W., Schwab, M. J., and Neev, D.: The late Quaternary limnological history of Lake Kinneret (Sea of Galilee), Israel, Quaternary Res., 63, 60–77, doi:10.1016/j.yqres.2004.09.004, 2005.

Heinrich, H.: Origin and consequences of cyclic ice rafting in the Northeast Atlantic Ocean during the past 130,000 years, Quaternary Res., 29, 142–152, doi:10.1016/0033-5894(88)90057-9, 1988.

Hemming, S. R.: Heinrich events: Massive late Pleistocene detritus layers of the North Atlantic and their global climate imprint, Rev. Geophys., 42, RG1005, doi:10.1029/2003rg000128, 2004.

Hershkovitz, I., Marder, O., Ayalon, A., Bar-Matthews, M., Yasur, G., Boaretto, E., Caracuta, V., Alex, B., Frumkin, A., Goder-Goldberger, M., Gunz, P., Holloway, R. L., Latimer, B., Lavi, R., Matthews, A., Slon, V., Mayer, D. B.-Y., Berna, F., Bar-Oz, G., Yeshurun, R., May, H., Hans, M. G., Weber, G. W., and Barzilai, O.: Levantine cranium from Manot Cave (Israel) foreshadows the first European modern humans, Nature, 520, 216–219, doi:10.1038/nature14134, 2015.

Horowitz, A.: Climatic and vegetational developments in northeastern Israel during Upper Pleistocene-Holocene times, Pollen et Spores, 13, 255–278, 1971.

Horowitz, A.: The Quarternary of Israel, Academic Press, New York, London, 1979.

Horowitz, A.: Palynology of arid lands, Elsevier, Amsterdam, 1992.

IPCC: Summary for Policymakers, in: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, edited by: Stocker, T. F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S. K., Boschung, J., Nauels, A., Xia, Y., Bex, V., and Midgley, P. M., Cambridge University Press, Cambridge, New York, 3–29, 2013.

Jacobson, G. L. and Bradshaw, R. H. W.: The Selection of Sites for Paleovegetational Studies, Quaternary Res., 16, 80–96, doi:10.1016/0033-5894(81)90129-0, 1981.

Jessen, K. and Milthers, V.: Stratigraphical and Paleontological Studies of Interglacial Fresh-Water Deposits in Jutland and Northwest Germany., Danmarks Geologiske Undersøgelse, 2, 1–379, 1928.

Kuhlwilm, M., Gronau, I., Hubisz, M. J., de Filippo, C., Prado-Martinez, J., Kircher, M., Fu, Q., Burbano, H. A., Lalueza-Fox, C., de la Rasilla, M., Rosas, A., Rudan, P., Brajkovic, D., Kucan, Ž., Gušic, I., Marques-Bonet, T., Andrés, A. M., Viola, B., Pääbo, S., Meyer, M., Siepel, A., and Castellano, S.: Ancient gene flow from early modern humans into Eastern Neanderthals, Nature, 530, 429–433, doi:10.1038/nature16544, 2016.

Kuijt, I. and Goring-Morris, N.: Foraging, Farming, and Social Complexity in the Pre-Pottery Neolithic of the Southern Levant: A Review and Synthesis, J. World Prehist., 16, 361–440, doi:10.1023/a:1022973114090, 2002.

Langgut, D., Almogi-Labin, A., Bar-Matthews, M., and Weinstein-Evron, M.: Vegetation and climate changes in the South Eastern Mediterranean during the Last Glacial-Interglacial cycle (86 ka): new marine pollen record, Quaternary Sci. Rev., 30, 3960–3972, doi:10.1016/j.quascirev.2011.10.016, 2011.

Lisiecki, L. E. and Raymo, M. E.: A Pliocene-Pleistocene stack of 57 globally distributed benthic δ^{18}O records, Paleoceanography, 20, PA1003, doi:10.1029/2004PA001071, 2005.

Litt, T.: Das Quartär als chronostratigraphische Einheit, Quaternary Science Journal, 56, 3–6, 2007.

Litt, T., Ohlwein, C., Neumann, F. H., Hense, A., and Stein, M.: Holocene climate variability in the Levant from the Dead Sea pollen record, Quaternary Sci. Rev., 49, 95–105, doi:10.1016/j.quascirev.2012.06.012, 2012.

Litt, T., Pickarski, N., Heumann, G., Stockhecke, M., and Tzedakis, P. C.: A 600,000 year long continental pollen record from Lake Van, eastern Anatolia (Turkey), Quaternary Sci. Rev., 104, 30–41, doi:10.1016/j.quascirev.2014.03.017, 2014.

Lowe, J. and Walker, M.: Reconstructing Quaternary Environments, 3 Edn., Routledge, Abingdon, New York, 2015.

Margari, V., Gibbard, P. L., Bryant, C. L., and Tzedakis, P. C.: Character of vegetational and environmental changes in southern Europe during the last glacial period; evidence from Lesvos Island, Greece, Quaternary Sci. Rev., 28, 1317–1339, doi:10.1016/j.quascirev.2009.01.008, 2009.

Marinova, E. and Atanassova, J.: Anthropogenic impact on vegetation and environment during the Bronze Age in the area of Lake Durankulak, NE Bulgaria: Pollen, microscopic charcoal, non-pollen palynomorphs and plant macrofossils, Rev. Palaeobot. Palyno., 141, 165–178, doi:10.1016/j.revpalbo.2006.03.011, 2006.

Masson-Delmotte, V., M. Schulz, Abe-Ouchi, A., Beer, A. G., J. , González Rouco, J. F., Jansen, E., Lambeck, K., Luterbacher, J., Naish, T., Osborn, T., Otto-Bliesner, B., Quinn, T., Ramesh, R., Rojas, M., Shao, X., and Timmermann, A.: Information from Paleoclimate Archives, in: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, edited by: Stocker, T. F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S. K., Boschung, J., Nauels, A., Xia, Y., Bex, V., and Midgley, P. M., Cambridge University Press, Cambridge, New York, 383–464, 2013.

Miller, N. F.: The Near East, in: Progress in Old World Palaeoethnobotany, edited by: Zeist, v., Wasylikowa, and Behre, Balkema, Rotterdam, 133–160, 1991.

Mix, A. C., Bard, E., and Schneider, R.: Environmental processes of the ice age: land, oceans, glaciers (EPILOG), Quaternary Sci. Rev., 20, 627–657, doi:10.1016/S0277-3791(00)00145-1, 2001.

Moore, P. D., Webb, J. A., and Collinson, M. E.: Pollen analysis, 2 Edn., Blackwell Scientific Publications, Oxford, 1991.

Mudie, P. J., Rochon, A., and Aksu, A. E.: Pollen stratigraphy of Late Quaternary cores from Marmara Sea: land-sea correlation and paleoclimatic history, Mar. Geol., 190, 233–260, doi:10.1016/S0025-3227(02)00349-3, 2002.

Müller, U. C., Pross, J., Tzedakis, P. C., Gamble, C., and Kotthoff, U.: The role of climate in the spread of modern humans into Europe, Quaternary Sci. Rev., 30, 273–279, doi:10.1016/j.quascirev.2010.11.016, 2011.

Nadel, D., Carmi, I., and Segal, D.: Radiocarbon dating of Ohalo II: Archaeological and methodological implications, J. Archaeol. Sci., 22, 811–822, doi:10.1016/0305-4403(95)90010-1, 1995.

Neugebauer, I., Brauer, A., Schwab, M. J., Waldmann, N. D., Enzel, Y., Kitagawa, H., Torfstein, A., Frank, U., Dulski, P., Agnon, A., Ariztegui, D., Ben-Avraham, Z., Goldstein, S. L., and Stein, M.: Lithology of the long sediment record recovered by the ICDP Dead Sea Deep Drilling Project (DSDDP), Quaternary Sci. Rev., 102, 149–165, doi:10.1016/j.quascirev.2014.08.013, 2014.

NGRIP members: High-resolution record of Northern Hemisphere climate extending into the last interglacial period, Nature, 431, 147–151, doi:10.1038/nature02805, 2004.

Niklewski, J. and Van Zeist, W.: A Late Quaternary pollen diagram from northwestern Syria, Acta Bot. Neerl., 19, 737–754, 1970.

Obreht, I., Zeeden, C., Schulte, P., Hambach, U., Eckmeier, E., Timar-Gabor, A., and Lehmkuhl, F.: Aeolian dynamics at the Orlovat loess–paleosol sequence, northern Serbia, based on detailed textural and geochemical evidence, Aeolian Research, 18, 69–81, doi:10.1016/j.aeolia.2015.06.004, 2015.

Özdoğan, M.: Archaeological Evidence on the Westward Expansion of Farming Communities from Eastern Anatolia to the Aegean and the Balkans, Curr. Anthropol., 52, S415–S430, doi:10.1086/658895, 2011.

Panagiotopoulos, K., Böhm, A., Leng, M. J., Wagner, B., and Schäbitz, F.: Climate variability over the last 92 ka in SW Balkans from analysis of sediments from Lake Prespa, Clim. Past, 10, 643–660, doi:10.5194/cp-10-643-2014, 2014.

Pickarski, N., Kwiecien, O., Langgut, D., and Litt, T.: Abrupt climate and vegetation variability of eastern Anatolia during the last glacial, Clim. Past, 11, 1491–1505, doi:10.5194/cp-11-1491-2015, 2015.

Quintana Krupinski, N. B., Marlon, J. R., Nishri, A., Street, J. H., and Paytan, A.: Climatic and human controls on the late Holocene fire history of northern Israel, Quaternary Res., 80, 396–405, doi:10.1016/j.yqres.2013.06.012, 2013.

Rahmstorf, S.: Ocean circulation and climate during the past 120,000 years, Nature, 419, 207–214, doi:10.1038/nature01090, 2002.

Rasmussen, S. O., Bigler, M., Blockley, S. P., Blunier, T., Buchardt, S. L., Clausen, H. B., Cvijanovic, I., Dahl-Jensen, D., Johnsen, S. J., Fischer, H., Gkinis, V., Guillevic, M., Hoek, W. Z., Lowe, J. J., Pedro, J. B., Popp, T., Seierstad, I. K., Steffensen, J. P., Svensson, A. M., Vallelonga, P., Vinther, B. M., Walker, M. J. C., Wheatley, J. J., and Winstrup, M.: A stratigraphic framework for abrupt climatic changes during the Last Glacial period based on three synchronized Greenland ice-core records: refining and extending the INTIMATE event stratigraphy, Quaternary Sci. Rev., 106, 14–28, doi:10.1016/j.quascirev.2014.09.007, 2014.

Rasmussen, T. L., Oppo, D. W., Thomsen, E., and Lehman, S. J.: Deep sea records from the southeast Labrador Sea: Ocean circulation changes and ice-rafting events during the last 160,000 years, Paleoceanography, 18, 1018, doi:10.1029/2001PA000736, 2003.

Richter, J., Hauck, T., Vogelsang, R., Widlok, T., Le Tensorer, J.-M., and Schmid, P.: “Contextual areas” of early Homo sapiens and their significance for human dispersal from Africa into Eurasia between 200 ka and 70 ka, Quatern. Int., 274, 5–24, doi:10.1016/j.quaint.2012.04.017, 2012a.

Richter, J., Melles, M., and Schäbitz, F.: Temporal and spatial corridors of Homo sapiens sapiens population dynamics during the Late Pleistocene and early Holocene, Quatern. Int., 274, 1–4, doi:10.1016/j.quaint.2012.06.009, 2012b.

Roberts, N.: Human-induced landscape change in South and Southwest Turkey during the later Holocene, in: Man’s Role in the Shaping of the Eastern Mediterranean Landscape, edited by: Bottema, S., Entjes-Nieborg, G., and van Zeist, W., Balkema, Rotterdam, 53–66, 1990.

Robinson, S. A., Black, S., Sellwood, B. W., and Valdes, P. J.: A review of palaeoclimates and palaeoenvironments in the Levant and Eastern Mediterranean from 25,000 to 5000 years BP: setting the environmental background for the evolution of human civilisation, Quaternary Sci. Rev., 25, 1517–1541, doi:10.1016/j.quascirev.2006.02.006, 2006.

Roeser, P., Franz, S. O., and Litt, T.: Aragonite and calcite preservation in sediments from Lake Iznik related to bottom lake oxygenation and water column depth, Sedimentology, Accepted Author Manuscript, doi:10.1111/sed.12306, 2016.

Roeser, P. A., Franz, S. O., Litt, T., Ülgen, U. B., Hilgers, A., Wulf, S., Wennrich, V., Ön, S. A., Viehberg, F. A., Çağatay, M. N., and Melles, M.: Lithostratigraphic and geochronological framework for the paleoenvironmental reconstruction of the last ~36 ka cal BP from a sediment record from Lake Iznik (NW Turkey), Quatern. Int., 274, 73–87, doi:10.1016/j.quaint.2012.06.006, 2012.

Rollefson, G. O. and Köhler-Rollefson, I.: Early neolithic exploitation patterns in the Levant: Cultural impact on the environment, Popul. Environ., 13, 243–254, doi:10.1007/bf01271025, 1992.

Roodenberg, J., van As, A., and Alpaslan Roodenberg, S.: Barcin Hüyük in the Plain of Yenişehir (2005-2006), Anatolica, 34, 53–60, doi:10.2143/ANA.32.2012551, 2008.

Roodenberg J. and Roodenberg, S. A. (Eds.): Life and Death in a Prehistoric Settlement in Northwest Anatolia: The Ilıpınar Excavations, Volume III, Nederlands Instituut voor het Nabije Oosten, Leiden, 2008.

Rossignol-Strick, M.: Sea-land correlation of pollen records in the eastern Mediterranean for the glacial-interglacial transition, Quaternary Sci. Rev., 14, 893–915, doi:10.1016/0277-3791(95)00070-4, 1995.

Sadori, L., Koutsodendris, A., Panagiotopoulos, K., Masi, A., Bertini, A., Combourieu-Nebout, N., Francke, A., Kouli, K., Joannin, S., Mercuri, A. M., Peyron, O., Torri, P., Wagner, B., Zanchetta, G., Sinopoli, G., and Donders, T. H.: Pollen-based paleoenvironmental and paleoclimatic change at Lake Ohrid (south-eastern Europe) during the past 500 ka, Biogeosciences, 13, 1423–1437, doi:10.5194/bg-13-1423-2016, 2016.

Sanchez Goñi, M. F. and Harrison, S. P.: Millennial-scale climate variability and vegetation changes during the Last Glacial: Concepts and terminology, Quaternary Sci. Rev., 29, 2823–2827, doi:10.1016/j.quascirev.2009.11.014, 2010.

Schiebel, V.: Vegetation and climate history of the southern Levant during the last 30,000 years based on palynological investigation, Dissertation, Rheinische Friedrich-Wilhelms-Universität Bonn, Bonn, 104 pp., 2013.

Schönwiese, C.-D.: Klimatologie, Ulmer, Stuttgart, 2008.

Shea, J. J.: Transitions or turnovers? Climatically-forced extinctions of Homo sapiens and Neanderthals in the east Mediterranean Levant, Quaternary Sci. Rev., 27, 2253–2270, doi:10.1016/j.quascirev.2008.08.015, 2008.

Shea, J. J.: Stone Tools in the Paleolithic and Neolithic Near East: A Guide, Cambridge University Press, New York, 2013.

Shumilovskikh, L. S., Tarasov, P., Arz, H. W., Fleitmann, D., Marret, F., Nowaczyk, N., Plessen, B., Schlütz, F., and Behling, H.: Vegetation and environmental dynamics in the southern Black Sea region since 18 kyr BP derived from the marine core 22-GC3, Palaeogeogr. Palaeocl., 337–338, 177–193, doi:10.1016/j.palaeo.2012.04.015, 2012.

Shumilovskikh, L. S., Fleitmann, D., Nowaczyk, N. R., Behling, H., Marret, F., Wegwerth, A., and Arz, H. W.: Orbital- and millennial-scale environmental changes between 64 and 20 ka BP recorded in Black Sea sediments, Clim. Past, 10, 939–954, doi:10.5194/cp-10-939-2014, 2014.

Shumilovskikh, L. S., Seeliger, M., Feuser, S., Novenko, E., Schlütz, F., Pint, A., Pirson, F., and Brückner, H.: The harbour of Elaia: A palynological archive for human environmental interactions during the last 7500 years, Quaternary Sci. Rev., 149, 167–187, doi:10.1016/j.quascirev.2016.07.014, 2016.

Straka, H.: Pollen- und Sporenkunde: eine Einfuhrung in die Palynologie, Fischer, Stuttgart, 238 pp., 1975.

Touchan, R., Akkemik, Ü., Hughes, M. K., and Erkan, N.: May–June precipitation reconstruction of southwestern Anatolia, Turkey during the last 900 years from tree rings, Quaternary Res., 68, 196–202, doi:10.1016/j.yqres.2007.07.001, 2007.

Turner, R., Roberts, N., Eastwood, W. J., Jenkins, E., and Rosen, A.: Fire, climate and the origins of agriculture: micro-charcoal records of biomass burning during the last glacial–interglacial transition in Southwest Asia, J. Quaternary Sci., 25, 371–386, doi:10.1002/jqs.1332, 2010.

Tzedakis, P. C.: The last climatic cycle at Kopais, central Greece, J. Geol. Soc. London, 156, 425–434, doi:10.1144/gsjgs.156.2.0425, 1999.

Tzedakis, P. C., Lawson, I. T., Frogley, M. R., Hewitt, G. M., and Preece, R. C.: Buffered Tree Population Changes in a Quaternary Refugium: Evolutionary Implications, Science, 297, 2044–2047, doi:10.1126/science.1073083, 2002.

Tzedakis, P. C., Frogley, M. R., Lawson, I. T., Preece, R. C., Cacho, I., and de Abreu, L.: Ecological thresholds and patterns of millennial-scale climate variability: The response of vegetation in Greece during the last glacial period, Geology, 32, 109–112, doi:10.1130/G20118.1, 2004.

Tzedakis, P. C., Hooghiemstra, H., and Pälike, H.: The last 1.35 million years at Tenaghi Philippon: revised chronostratigraphy and long-term vegetation trends, Quaternary Sci. Rev., 25, 3416–3430, doi:10.1016/j.quascirev.2006.09.002, 2006.

Ülgen, U. B., Franz, S. O., Biltekin, D., Çagatay, M. N., Roeser, P. A., Doner, L., and Thein, J.: Climatic and environmental evolution of Lake Iznik (NW Turkey) over the last ~4700 years, Quatern. Int., 274, 88–101, doi:10.1016/j.quaint.2012.06.016, 2012.

Vaks, A., Bar-Matthews, M., Ayalon, A., Matthews, A., Frumkin, A., Dayan, U., Halicz, L., Almogi-Labin, A., and Schilman, B.: Paleoclimate and location of the border between Mediterranean climate region and the Saharo–Arabian Desert as revealed by speleothems from the northern Negev Desert, Israel, Earth Planet. Sc. Lett., 249, 384–399, doi:10.1016/j.epsl.2006.07.009, 2006.

Valsecchi, V., Sánchez-Goñi, M. F., and Londeix, L.: Vegetation dynamics in the Northeastern Mediterranean region during the past 23 000 yr: insights from a new pollen record from the Sea of Marmara, Clim. Past, 8, 1941–1956, doi:10.5194/cp-8-1941-2012, 2012.

van Zeist, W. and Bottema, S.: Palynological investigations in western Iran, Palaeohistoria, 19, 19–85, 1977.

van Zeist, W., Baruch, U., and Bottema, S.: Holocene palaeoecology of the Hula area, northeastern Israel, in: A timeless vale. Archaeological and related essays on the Jordan Valley in honour of Gerrit van der Kooij on the occasion of his sixty-fifth birthday, edited by: Kaptijnand, E. and Petit, L. P., Archaeological Studies Leiden University, Leiden University Press, Leiden, 29–64, 2009.

Weinstein-Evron, M.: The paleoecology of the early Wurm in the Hula basin, Israel, Paléorient, 9, 5–19, doi:10.3406/paleo.1983.4328, 1983.

Weinstein, M.: The late Quaternary vegetation of the northern Golan, Pollen et Spores, 18, 553–562, 1976.

Whitlock, C. and Larsen, C.: Charcoal as a Fire Proxy, in: Tracking Environmental Change Using Lake Sediments. Volume 3: Terrestrial, Algal, and Siliceous Indicators, edited by: Smol, J. P., Birks, H. J. B., Last, W. M., Bradley, R. S., and Alverson, K., Kluwer Academic Publishers, Dordrecht, 75–97, 2001.

Wick, L., Lemcke, G., and Sturm, M.: Evidence of Lateglacial and Holocene climatic change and human impact in eastern Anatolia: high-resolution pollen, charcoal, isotopic and geochemical records from the laminated sediments of Lake Van, Turkey, Holocene, 13, 665–675, doi:10.1191/0959683603hl653rp, 2003.

Zohary, M.: Plant Life of Palestine: Israel and Jordan, The Ronald Press Company, New York, 1962.

Zohary, M.: Geobotanical Foundations of the Middle East, Gustav Fischer Verlag, Stuttgart, 1973.

2 Impacts of climate and humans on the vegetation in northwestern Turkey: palynological insights from Lake Iznik since the Last Glacial[1]

2.1 Abstract

The Marmara region in northwestern Turkey provides a unique opportunity for studying the vegetation history in response to climate changes and anthropogenic impacts because of its location between different climate and vegetation zones and its long settlement history. Geochemical and mineralogical investigations of the largest lake in the region, Lake Iznik, already registered climate-related changes of the lake level and the lake mixing. However, a palynological investigation encompassing the Late Pleistocene to Middle Holocene was still missing. Here, we present the first pollen record of the last ca. 31 ka cal BP (calibrated kilo years before 1950) inferred from Lake Iznik sediments as an independent proxy for paleoecological reconstructions. Our study reveals that the vegetation in the Iznik area changed generally between (a) steppe during glacials and stadials indicating dry and cold climatic conditions, (b) forest-steppe during interstadials indicating milder and moister climatic conditions, and (c) oak-dominated mesic forest during interglacials indicating warm and moist climatic conditions. Moreover, a pronounced succession of pioneer trees, cold temperate, warm temperate, and Mediterranean trees appeared since the Lateglacial. Rapid climate changes, which are reflected by vegetation changes, can be correlated with Dansgaard-Oeschger (DO) events such as DO-4, DO-3, and DO-1, the Younger Dryas, and probably also the 8.2 event. Since the mid-Holocene, the vegetation was influenced by anthropogenic activities. During early settlement phases, the distinction between climate-induced and human-induced changes of the vegetation is challenging. Still, evidence for human activities consolidates since the Early Bronze Age (ca. 4.8 ka cal BP): cultivated trees, crops, and secondary human indicator taxa appeared, and forests were cleared. Subsequent fluctuations between extensive agricultural uses and regenerations of the natural vegetation become apparent.

2.2 Introduction

The reconstruction of past climatic and environmental conditions is crucial to understand the living conditions and migration processes of former societies. After the first spread of modern humans into Europe during the Last Glacial (e.g., Benazzi et al., 2011; Higham et al., 2011), different population dynamics into and out of Europe followed. These population dynamics also include the spatial expansion of farming and husbandry, which happened between ca. 11 600 and 5500 years ago. The Marmara region, situated between the Mediterranean Sea and the Black Sea at the principal corridor of human dispersal from Africa via the Middle East to the Balkans, functioned as an important bottleneck for all migrated societies (Richter et al., 2012).

---

[1] Chapter 2 is based on Miebach, A.; Niestrath, P.; Roeser, P. & Litt, T. (2016): Impacts of climate and humans on the vegetation in northwestern Turkey: palynological insights from Lake Iznik since the Last Glacial. Climate of the Past 12: 575–593. Doi:10.5194/cp-12-575-2016.

The Last Glacial is characterized by unstable climatic conditions changing between stadial (and glacial) conditions and milder interstadial conditions. Several rapid climate changes described as Dansgaard-Oeschger (DO) events (Dansgaard et al., 1982) and Heinrich events (Heinrich, 1988; Bond et al., 1992) occurred. DO events are associated with an abrupt warming followed by a gradual re-cooling, which are well documented in the Greenland ice core records (e.g., NGRIP members, 2004). Heinrich events are associated with cold periods (also called Heinrich Stadials (HS); Sanchez Goñi and Harrison, 2010), when ice-rafted debris deposited in the North Atlantic due to massive discharges of icebergs (Bond et al., 1992). Climatic imprints related to DO events and HS are documented in many northern-hemispheric records (e.g., Hemming, 2004; Sanchez Goñi and Harrison, 2010; Müller et al., 2011; Panagiotopoulos et al., 2014; Pickarski et al., 2015). However, the magnitude, nature, and duration of each event might have varied from region to region (Sanchez Goñi and Harrison, 2010). Therefore, further records, also in Turkey, are needed to establish a complete picture of the influence of rapid climate changes on environmental conditions (Fletcher et al., 2010).

Lake Iznik, the largest lake in the Marmara region, serves as a valuable archive to study the relationship between vegetation, climate, and anthropogenic activities. The detection of human impacts on the vegetation is particularly interesting because the eastern Marmara region has a long occupation history, and archaeological settlements are in close proximity to Lake Iznik (e.g., Roodenberg and Roodenberg, 2008).

Previous studies reconstructed the paleoenvironmental and tectonic history of the Iznik Basin and investigated Lake Iznik's recent and paleo-limnology since the late Pleistocene based on seismicity, sedimentology, geochemistry, and mineralogy (Alpar et al., 2003; Franz et al., 2006; Öztürk et al., 2009; Roeser et al., 2012; Ülgen et al., 2012; Viehberg et al., 2012; Roeser, 2014). Those studies also revealed climate-related changes of the lake level and the lake mixing (Roeser et al., 2012; Ülgen et al., 2012; Roeser, 2014). A preliminary pollen analysis inferred from Lake Iznik sediments was published by Ülgen et al. (2012). The pollen record, which is only presented in ecological plant groups, encompasses the last 2400 years. A palynological investigation of sediments from Lake Iznik encompassing the late Pleistocene to late Holocene was still missing.

To provide a better view on the environmental conditions in the Marmara region during the last ca. 31 000 years, we investigated the pollen assemblage and selected non-pollen palynomorphs (NPP) of a ca. 18 m composite profile from Lake Iznik. It comprises a continuous and undisturbed sediment record with a robust chronology (Roeser et al., 2012; Ülgen et al., 2012; Roeser, 2014). Here, we present a new vegetation and climate study, which also concerns human activities in the catchment area of Lake Iznik.

2.3 Study area

2.3.1 Regional setting

Lake Iznik (Turkish: İznik Gölü) is located in the southeast of the Turkish Marmara region (Fig. 2.1). The Marmara region is a tectonically active area surrounding the Marmara Sea. Lake Iznik lies at the middle strand of the North Anatolian Fault, which is the boundary between the Anatolian and Eurasian plate (Öztürk et al., 2009).

With a surface area of 313 km^2, 32 km in length and 12 km in width, Lake Iznik is the largest lake in the Marmara region (Fig. 2.2). Lake Iznik is situated 85 m above present mean sea level (m a.s.l.) and reaches a maximal water depth of 80 m (Wester, 1989; Franz et al., 2006). The alkaline freshwater lake receives fluvial input from five main rivers (Nadir, Kuru, Kara, Kiran, and Sölöz), while the only output stream is Karsak (Viehberg et al., 2012). The catchment area is about 920 km^2 (Wester, 1989). Several mountain ridges surround the Iznik Basin: Samanli Mountains in the north, Gemiç Mountains in the southwest, and Katirli Mountains in the south. Their summits range from 810 to 1293 m a.s.l. (Öztürk et al., 2009).

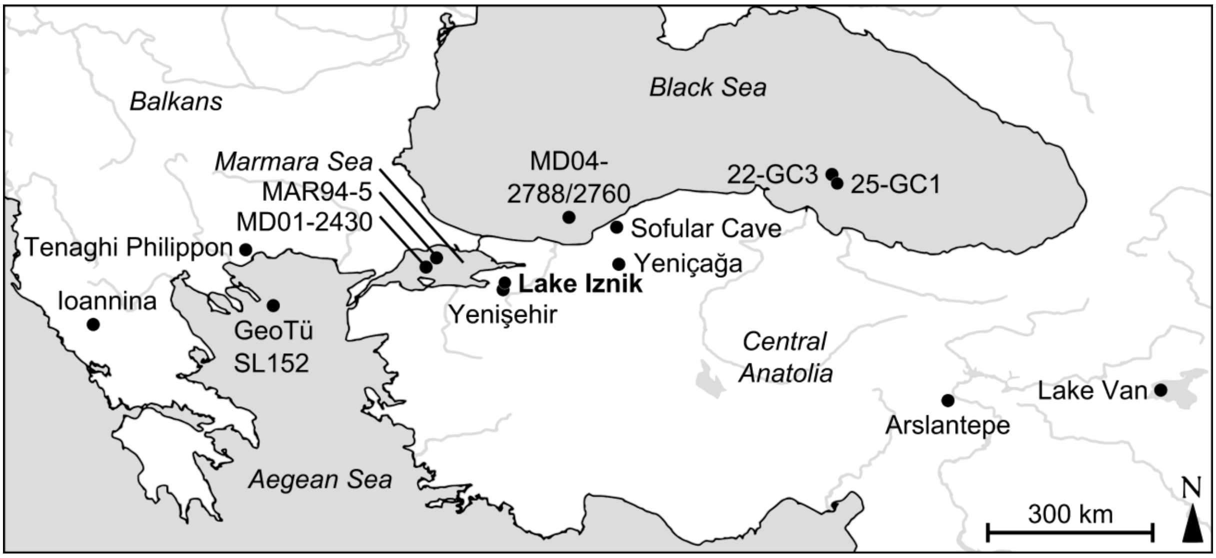


Figure 2.1: Regional overview modified from Roeser et al. (2012). Dots indicate Lake Iznik (this study) and paleo records mentioned in the discussion: Ioannina (Lawson et al., 2004), Tenaghi Philippon (Tzedakis et al., 2004; Müller et al., 2011), GeoTü SL152 (Kotthoff et al., 2008), MAR94-5 (Mudie et al., 2002), MD01-2430 (Valsecchi et al., 2012), Yenişehir (Bottema et al., 2001), MD04-2788/2760 (Kwiecien et al., 2009), Sofular Cave (Fleitmann et al., 2009; Göktürk et al., 2011), Yeniçağa (van Zeist and Bottema, 1991), 22-GC3 (Shumilovskikh et al., 2012), 25-GC1 (Shumilovskikh et al., 2014), Arslantepe (Masi et al., 2013), and Lake Van (Wick et al., 2003; Litt et al., 2009).

2.3.2 Current climate

Lake Iznik's catchment area is situated in a climatic transition zone, which is influenced by the Mediterranean climate and the Pontic climate. Warm, dry summers and mild, moist winters are typical for the Mediterranean climate (Köppen, 1900). In contrast, the Pontic climate is characterized by an absence of summer drought due to higher precipitation throughout the year and lower mean temperatures (Kürschner et al., 1997). The annual average air temperature at the Iznik Basin is around 14.4 °C, and the monthly average minimal air temperature never drops below 0 °C (Wester, 1989; Table 2.1). Since Lake Iznik is surrounded by mountain ranges, one can find notable lower average temperatures close by

(Akbulak, 2009). Most precipitation falls in winter and spring, whereas June to September are arid months. A gradient in precipitation from west to east is characteristic not only for the Iznik Basin (Orhangazi – Iznik; Table 2.1) but also for the whole region (Aegean Sea/Marmara Sea – Central Anatolia; Mayer and Aksoy, 1986; Wester, 1989). Precipitation can rise up to about 1200 mm in higher elevations near Lake Iznik (Akbulak, 2009). The prevailing wind direction is west in summer and east in autumn and winter. The wind is unstable in spring and changes directions (Wester, 1989).

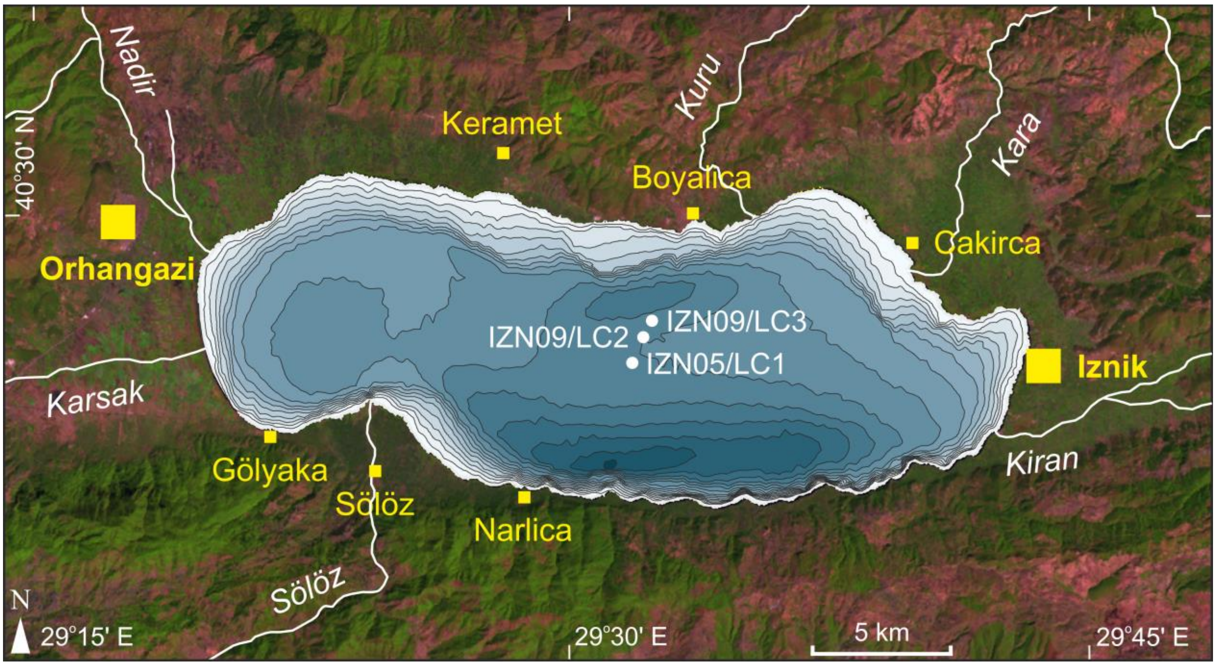


Figure 2.2: Lake Iznik with bathymetric curves in 5 m intervals modified from Roeser et al. (2012). Dots indicate the coring locations, and squares indicate settlements.

Table 2.1: Average climate data and elevation of Iznik and Orhangazi (Wester, 1989; see Fig. 2.2 for the locations).

	Elevation (m a.s.l.)	Air temperature (°C)			Precipitation (mm)			Evaporation (mm)
		year	Jan	Jul	year	Nov–Apr	May–Oct	year
Iznik	88	14.4	6.9	23.8	552	351	201	718
Orhangazi	95	14.4	5.2	24.2	743	507	236	648

2.3.3 Current vegetation

The potential natural vegetation of northwestern Anatolia is divided into five vegetation zones, from which three directly influence the catchment of Lake Iznik (Fig. 2.3).

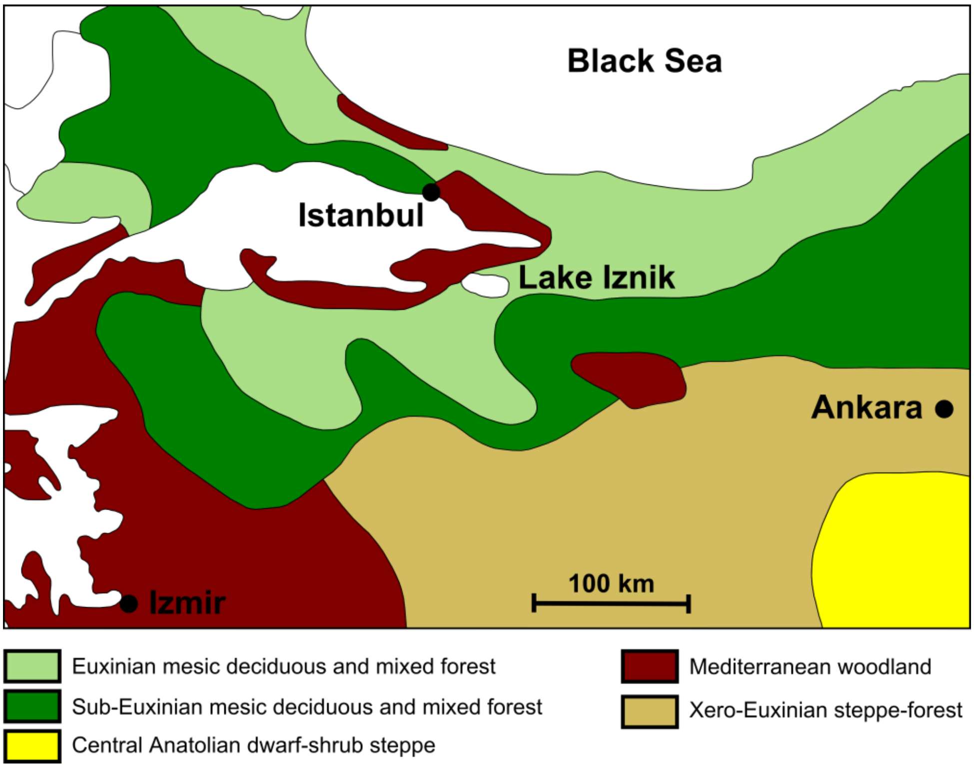


Figure 2.3: Natural potential vegetation of northwestern Turkey redrawn from Zohary (1973).

A band of Euxinian and sub-Euxinian mesic deciduous and mixed forest extends along the southern and eastern coasts of the Black Sea (Zohary, 1973; Shumilovskikh et al., 2012). In northwestern Anatolia, it reaches into Thrace (European Turkey) and south of the Marmara Sea almost to the Aegean Sea. The forest is dominated by oriental beech (*Fagus orientalis*) and deciduous oaks (Zohary, 1973). Other important summer-green trees include *Fagus sylvatica*, *Alnus glutinosa*, *Acer campestre*, *Populus tremula*, *Carpinus*, *Fraxinus*, and *Ulmus* (Mudie et al., 2002). Conifers like *Pinus sylvestris*, *P. nigra*, *Abies nordmanniana*, and *Picea orientalis* are present in low altitudes, but they become more frequent in higher altitudes (Zohary, 1973). The Pontic forest is associated with more than 600 mm mean annual precipitation (Roberts and Wright, 1993). Zohary (1973) divided the vegetation zone into an Euxinian type near the coast and a more continental sub-Euxinian type. The rain shadow of the Pontic Mountains favors the latter type, which is characterized by a high amount of *Carpinus* and *Pinus nigra*. The natural tree line near Lake Iznik reaches an elevation of about 2000 m (Louis, 1939).

The Aegean coasts and southeastern coasts of the Marmara Sea are characterized by a climax of Mediterranean woodland. According to Zohary (1973), there is an evergreen subzone from sea level to an elevation of 1000 m and an oro-Mediterranean subzone reaching up to 1600 m. The evergreen subzone is dominated by *Quercus calliprinos*, *Olea europaea*, *Ceratonia siliqua*, *Myrtus communis*, *Phillyrea media*, *Arbutus*, and *Pistacia*. But there are also some deciduous and coniferous elements like *Quercus infectoria*, *Q. ithaburensis*, *Styrax officinalis*, *Crataegus azarolus*, *Spartium junceum*, *Juniperus phoenica*, and *Pinus brutia* (Zohary, 1973; van Zeist et al., 1975). The oro-Mediterranean subzone is dominated by summer-green trees and conifers. Important elements are deciduous oaks (mainly *Quercus cerris*) and pines (mainly *Pinus nigra*). Additionally, the range of characteristic arboreal taxa includes: *Ostrya carpinifolia*, *Castanea sativa*, *Fraxinus ornus*, *Cotinus coggygria*, *Fontanesia phillyreoides*, *Acer*, *Juniperus*, *Cornus*, *Buxus*, several Rosaceae (e.g., *Crataegus monogyna*), and several Fabaceae (e.g., *Colutea arborescens*; Zohary, 1973).

However, the potential natural vegetation differs considerably from the vegetation one will find nowadays, which is shaped by human activities of several thousand years (Mayer and Aksoy, 1986). Due to agriculture (e.g., olive cultivation, cereal cropping, and husbandry), forests were cleared, large areas were overgrazed, landscapes were burned, and soils eroded (Zohary, 1973; Mayer and Aksoy, 1986). Former Mediterranean woodlands degraded to macchia vegetation with *Arbutus*, *Juniperus*, *Pistacia*, *Phillyrea latifolia*, *Spartium junceum*, and evergreen oaks (Kürschner et al., 1997; Atalay et al., 2014). In case this xeromorphic shrub vegetation were further overexploited, it degraded to phrygana vegetation. These are open landscapes with herbs and dwarf shrubs, which are often thorned (Kürschner et al., 1997). An important element of the Eastern Mediterranean phrygana is the dwarf shrub *Sarcopoterium spinosum*, which benefits from land degradation and extensive grazing (Le Houèrou, 1981; Bottema and Woldring, 1990).

2.4 Material and methods

2.4.1 Core setting, composite profile, and age-depth model

For the current study, a composite profile was constructed by using different sediment cores, which were collected in two separate coring campaigns. All of these cores descended from the central sedimentary ridge of Lake Iznik, which separates the northern and the southern basin, at a water depth of ca. 50 m (Fig. 2.2). The cores were recovered from floating platforms with the help of percussion piston corers (Roeser et al., 2012; Ülgen et al., 2012).

Sediment samples for pollen analyses originated from different cores: core IZN05/LC1 (coring location: 40°26.033 N, 29°31.999 E; recovered in summer 2005) from the composite profile IZN05/SC4E&LC1 (Ülgen et al., 2012) and cores IZN09/LC2 (coring location: 40°26.57 N, 29°32.35 E) and IZN09/LC3 (coring location: 40°26.92 N, 29°32.61 E; both recovered in autumn 2009) from the composite profile IZN09/LC2&LC3 (Roeser et al., 2012).

The composite profiles IZN05/SC4E&LC1 and IZN09/LC2&LC3 could be clearly correlated through Ca/Ti and Ca/Fe ratios, respectively, each supported by lithology (Ülgen et al., 2012: Fig. 5; Roeser et al., 2012: Appendix A). The tie point between the two composite profiles is a tephra from a Vesuvius eruption, an Avellino Pumice (AP) tephra, which was geochemically identified in both records (Ülgen et al., 2012; Roeser et al., 2012). The tephra was dated to 3945 ± 10 a cal BP (Sevink et al., 2011). The finding at Lake Iznik represents the easternmost evidence for the AP tephra, which is an important chronostratigraphic marker for a direct comparison with other paleo records (Çağatay et al., 2015), e.g., Lago Grande di Monticchio, Italy (Allen et al., 2002; Wulf et al., 2004) or Lake Shkodra, Albania and Montenegro (Sulpizio et al., 2010; Sadori et al., 2015). The final composite profile has a composite length of ca. 18 m (Roeser et al., 2012). The age-depth model from Roeser (2014) was extended with dates from core IZN05/LC1 (Ülgen et al., 2012) in order to expand it to recent times (Roeser et al., 2016).

2.4.2 Palynological analyses

33 sediment samples from core IZN05/LC1 were taken in a mean resolution of 12.6 cm ranging from the uppermost part of the core (0.51 m composite depth) to the AP tephra (4.58 m composite depth). After a first low-resolution screening of the composite profile IZN09/LC2&LC3, additional samples were processed in sections where climatic events were already known from geochemical analysis (Roeser et al., 2012; Roeser, 2014), the temporal resolution was very low, or palynological events were detected. Finally, 78 sediment samples from composite profile IZN09/LC2&LC3 were taken in a mean resolution of 17.5 cm ranging from the AP tephra to the end of the record (18.14 m composite depth). All samples had a sediment volume of mostly ca. 4 cm^3 (sampled with plastic syringes).

For the pollen preparation of the 111 sediment samples, we followed a standard protocol described in Faegri and Iversen (1989). The chemical treatment included 10 % hot hydrochloric acid (HCl) to remove carbonates (10 minutes), 40 % hydrofluoric acid (HF) to remove silicates (at least 48 hours), 10 % hot HCl (10 minutes), glacial acetic acid ($C_2H_4O_2$), hot acetolysis with 1 part concentrated sulfuric acid (H_2SO_4) and 9 parts concentrated acetic anhydrite ($C_4H_6O_3$) to remove cellulose (max. 3 minutes), and $C_2H_4O_2$. Coarser particles than 200 µm and finer particles than 10 µm were removed by sieving and ultrasonic sieving, respectively. Lycopodium tablets with 18 584 ± 371 spores were added to each sample as markers to calculate absolute pollen and NPP concentrations (Stockmarr, 1971). With the help of the concentration and sedimentation rates, influx (pollen accumulation) rates were calculated. Samples were preserved in glycerol and were stained with safranin.

Microscopic analyses were carried out with Zeiss Axio Lab.A1 light microscopes using a magnification of 400. The pollen reference collection of the Steinmann Institute (University of Bonn) and palynomorph keys (Faegri and Iversen, 1989; Moore et al., 1991; Reille, 1995, 1998, 1999; Chester and Raine, 2001; Beug, 2004) were used for the palynomorph identification. We mainly followed Beug (2004) for the nomenclature of pollen types. A minimum of 500 terrestrial pollen grains were counted in each sample (joint analyses by Phoebe Niestrath (0.51–4.58 m) and Andrea Miebach (4.58–18.14 m)). Obligate aquatic plants were excluded from the total pollen sum to exclude local taxa growing in the lake (Moore et al., 1991). Furthermore, destroyed, immature, and unknown pollen were excluded from the total pollen sum, which was used to calculate percentages of the pollen assemblage. Pollen types were grouped as follows: conifers, arid trees and shrubs (*Ephedra*, *Haloxylon*, *Hippophaë rhamnoides*), Mediterranean trees and shrubs (*Celtis*, *Ceratonia siliqua*, *Fraxinus ornus*, *Olea europaea*, *Phillyrea*, *Pistacia*, evergreen *Quercus*, *Vaccinium* type), temperate trees and shrubs (all other trees and shrubs), steppic herbs (*Artemisia*, Chenopodiaceae), and other herbs.

Pollen diagrams were prepared with Tilia, Version 1.7.16 (©1991–2011 Eric C. Grimm). A stratigraphically constrained cluster analysis using a square root transformation was applied by CONISS (Grimm, 1987). All taxa with more than 2 % of the total pollen sum and the sum of arboreal pollen (AP) were used for the cluster analysis. On this basis and visual pattern, local pollen assemblage zones (LPAZ) were determined.

2.5 Results and discussion

Selected pollen and spore data are presented in Fig. 2.4. According to the present age-depth model (Roeser et al., 2016), the temporal resolution of the record varies between 1139 and 57 years with an average of 278 years. Eight local pollen assemblage zones (LPAZ) were defined and are summarized in Table 2.2. The LPAZ are in agreement with previously defined lithological units, which are known to relate to specific climate phases (Roeser et al., 2012; Roeser, 2014). A complete pollen diagram with all taxa can be found in the supplementary material.

2.5.1 MIS 3-2 transition: ca. 31.1–28.4 ka cal BP (LPAZ 8)

Lake Iznik’s LPAZ 8 corresponds to the transition of Marine Isotope Stages (MIS) 3 and 2 (definition after Lisiecki and Raymo, 2005). The pollen assemblage documents a predominance of steppe vegetation with dwarf shrubs, herbs, and grasses dominated by wormwood (*Artemisia*), Tubuliflorae, Chenopodiaceae, and Poaceae (Fig. 2.4). Such a vegetation composition suggests generally dry and cold conditions. Still, climatic conditions allowed limited occurrences of arboreal taxa, especially pines (*Pinus*). Low to moderate pollen concentrations suggest a rather sparse vegetation cover.

However, two distinct rapid vegetation changes are evident, which are characterized by an increase of grasses (Poaceae) followed by a spread of pines, deciduous oaks (*Quercus*), and Cupressaceae (*Juniperus* type). Moreover, cold-tolerant trees like alders (*Alnus*) and firs (*Abies*) occurred in limited amounts. The decrease of steppic elements and arid-tolerant trees like common seabuckthorn (*Hippophaë rhamnoides*) together with a spread of trees and shrubs suggests increasing available moisture and higher temperatures, i.e., interstadial conditions. The vegetation was probably similar to today’s xero-Euxinian steppe forest (Fig. 2.3), which is characterized by 300–600 mm mean annual precipitation (Roberts and Wright, 1993). These rapid vegetation changes can be correlated to Dansgaard-Oeschger (DO) events DO-4 and DO-3 (definition of term after Rasmussen et al., 2014). DO events originated in the North Atlantic and were transferred by atmospheric and oceanic circulations into the Eastern Mediterranean (Tzedakis et al., 2004). During DO interstadials, the Iznik basin was probably climatically advantaged for the spread of trees and shrubs, especially in low altitudes and at south-facing slopes. The complex topography allowed plants to move in altitudinal direction and resulted in many microhabitats with probably favorable microclimates. However, the warm and moist phases were not strong or long enough to allow the occurrence of warm temperate trees and Mediterranean sclerophylls. The rapid but short-term expansion of trees and shrubs indicates that glacial refuge areas for temperate taxa were nearby.

Table 2.2: Local pollen assemblage zones (LPAZ) with composite depths, ages, the number of pollen samples, the temporal resolution, main components of the pollen assemblage (AP: arboreal pollen, NAP: non-arboreal pollen, percentages refer to the total pollen sum and give minimal and maximal values for the respective LPAZ), pollen concentrations (PC), definitions of lower boundaries (LB), and the inferred dominant vegetation type.

LPAZ	Depth (m)	Age (ka cal BP)	No. of pollen samples/temporal resolution (years)	Pollen assemblage	Dominant vegetation type
(1) *Olea europaea* LPAZ	0.51–2.65	0.6–2.2	17/102	AP: predominance with increasing trend: 71.4–91.6 %, high amounts of deciduous *Quercus* and *Pinus*, maximum of *Olea europaea* (0.6–28.3 %), plateau of *Juglans regia*. NAP: Poaceae (2.2–7.8 %) and Cerealia type (0.5–5.9 %) are most abundant. PC: moderate to high. LB: increase of *Olea europaea* and *Juglans regia*, decrease of deciduous *Quercus*	Mixed forest with some Mediterranean elements; strong anthropogenic exploitation on the natural vegetation and fruit and cereal cropping
(2) Cerealia type LPAZ	2.65–3.97	2.2–3.5	11/116	AP: predominance with rapid decrease followed by an increasing trend: 54.5–77 %, mainly deciduous *Quercus*, *Pinus*, and *Fagus*. NAP: Poaceae (4–16.5 %) and Cerealia type (2.4–11 %) are most abundant. PC: low to moderate. LB: increase of NAP, Poaceae, Cerealia type, Liguliflorae, Tubuliflorae, and *Vaccinium* type, decrease of AP, deciduous *Quercus*, *Pinus*	Mixed forest with some Mediterranean elements; strong anthropogenic exploitation on the natural vegetation and cereal cropping
(3) Deciduous *Quercus* LPAZ	3.97–9.16	3.5–9.0	32/179	AP: predominance: 63.2–93.1 %, mainly deciduous *Quercus*, *Fagus*, and *Carpinus/Ostrya*, increasing but unstable values of *Pinus*, peak of *Olea europaea* (0–6.9 %). NAP: Poaceae (1.5–16.3 %) is most abundant, peak of Liguliflorae (0–5.9 %). PC: rapid fluctuations between low and high. LB: increase of *Juniperus* type, decrease of *Sanguisorba minor* type, *Ulmus*/*Zelkova*, and *Alnus*	Diverse deciduous and mixed forest dominated by oaks with an increasing influence of pines
(4) *Sanguisorba minor* type LPAZ	9.16–10.27	9.0–12.1	5/664	AP: predominance with increasing trend: 67.5–82.2 %, mainly deciduous *Quercus*, plateau of *Ulmus/Zelkova*. NAP: Poaceae (9.8–17.1 %) and *Sanguisorba minor* type (0.2–4.5 %) are most abundant. PC: high. LB: increase of AP and deciduous *Quercus*, decrease of *Artemisia*	Full development of deciduous forest dominated by oaks, which get successively accompanied by cool-temperate and warm-temperate species

Table 2.2: continued

LPAZ	Depth (m)	Age (ka cal BP)	No. of pollen samples/temporal resolution (years)	Pollen assemblage	Dominant vegetation type
(5) Poaceae-deciduous *Quercus* LPAZ	10.27–11.13	12.1–15.0	10/314	AP: strong increase up to predominance: 33.7–67.1 %, mainly due to strong increase of deciduous *Quercus* (9.7–51.8 %), peak of *Pinus*, increase of *Alnus.* NAP: initial predominance but with rapid decrease, two peaks of Poaceae (13.5–40.6 %), weak peak of Chenopodiaceae (2–7 %). PC: moderate to high with one peak. LB: increase of AP, deciduous *Quercus*, and *Pinus*, decrease of NAP and Chenopodiaceae	Establishment of oak dominated woodland (with one weak and one stronger setback) and an decreasing influence of steppe
(8) *Artemisia*-*Juniperus* type LPAZ	11.13–12.91	15.0–18.4	8/428	AP: *Pinus*, *Juniperus* type, *Betula*, and deciduous *Quercus* are most abundant, maximum of *Ephedra* (0.2–2.6 %). NAP: predominance: 77.4–82.3 %, mainly *Artemisia*, Poaceae, and Chenopodiaceae. PC: moderate. LB: increase of *Artemisia*, *Juniperus* type, and *Betula*, decrease of Tubuliflorae, Liguliflorae, *Hippophaë rhamnoides*, and *Pinus*	Productive dwarf shrub steppe with scattered stands of pioneer trees
(7) *Hippophaë rhamnoides*-Tubuliflorae LPAZ	12.91–16.55	18.4–28.4	18/554	AP: high amounts of *Pinus* (6.5–26.4 %), maximum of *Hippophaë rhamnoides* (1.7–18.9 %). NAP: predominance with stable assemblage and abundance: 52.1–83.9 %, mainly *Artemisia*, Tubuliflorae, Poaceae, Chenopodiaceae, and Liguliflorae. PC: very low. LB: increase of NAP, *Artemisia*, and Tubuliflorae, decrease of AP and deciduous *Quercus*	Open steppe with very low vegetation cover
(8) *Artemisia*-deciduous *Quercus* LPAZ	16.55–18.14	28.4–31.1	11/259	AP: *Pinus* (4.2–26.3 %) and deciduous *Quercus* (0.6–12.5 %) are most abundant and peak twice. NAP: predominance with rapid fluctuations: 56–90.6 %, mainly *Artemisia*, Poaceae, Chenopodiaceae, and Tubuliflorae. PC: low to moderate. LB: not defined (end of record)	Fluctuation between open dwarf shrub steppe and forest steppe with scattered trees and shrubs

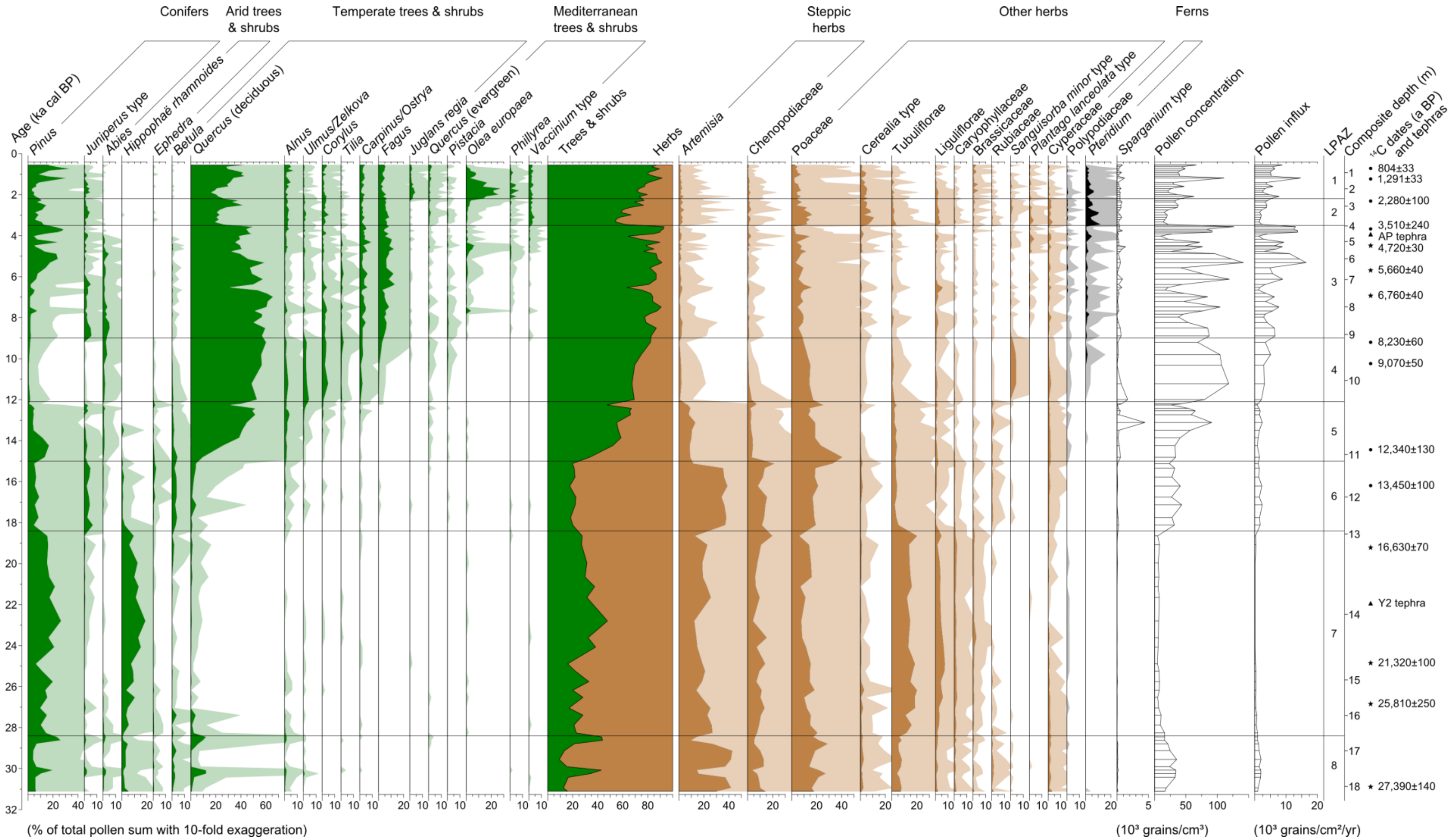


Figure 2.4: Pollen diagram inferred from Lake Iznik sediments with selected terrestrial plants in percentages, selected aquatic plants in concentrations, total pollen concentrations, total pollen influxes (pollen accumulations), and local pollen assemblage zones (LPAZ). Radiocarbon dates from plant remains (circles) and bulk organic (stars) as well as tephra positions according to Ülgen et al. (2012) and Roeser (2014) are marked.

The sparse vegetation cover in the Iznik area during stadial conditions is supported by low loads of terrestrial organic material into Lake Iznik documented by geochemical indicators, e.g., low ratios of total organic carbon and total nitrogen (TOC/TN; Roeser, 2014; Fig. 2.5). During DO-4 and DO-3, the lacustrine bioproductivity and endogen carbonate production, which are expressed by the calcium/titanium (Ca/Ti) ratio, increase simultaneously with arboreal pollen (AP) percentages in response to increased summer temperatures (Roeser et al., 2012; Fig. 2.5). Thus, our new pollen data set complements and confirms the former identification of DO events based on multi-proxy analysis (Roeser, 2014). An almost absence of the green algae *Pediastrum* and *Botryococcus* and the occurrence of dinoflagellate cysts of *Spiniferites cruciformis* at Lake Iznik (Fig. 2.5) suggest a low aquatic bioproductivity and oligotrophic conditions (low nutrient level; Jankovská and Komárek, 2000; Kouli et al., 2001). Increasing *Spiniferites cruciformis* amounts might be a result of higher water temperatures (Shumilovskikh et al., 2014).

The comparison of this study to vegetation studies from the southern Black Sea (Shumilovskikh et al., 2014; Fig. 2.6) and the Marmara Sea (core MAR94-5; Mudie et al., 2002) suggests a rather uniform vegetation in northwestern Turkey. However, higher pollen concentrations and higher abundances of AP in core MAR94-5 suggest a denser vegetation and more favorable conditions for tree growth in the central Marmara region (Mudie et al., 2002). The spread of deciduous oaks during DO events seems to be a general pattern in the northeastern Mediterranean, although several pollen records do not show a response to every interstadial. In fact, climatic conditions during DO-3 and DO-4 were probably still too harsh or favorable conditions were too short-lasting that several records do not show significant changes in the vegetation (Fletcher et al., 2010 and references therein).

A temporal offset of the Lake Iznik record is recognized by comparing it to the NGRIP $\delta^{18}O$ record (NGRIP members, 2004; Fig. 2.6) and the isotopic record from the well-dated Sofular Cave in northern Anatolia (Fleitmann et al., 2009; Fig. 2.6). Fleitmann et al. (2009) already described an age difference for the onset of DO-4 and DO-3 of the Sofular Cave compared to the NGRIP data of 586 and 277 years, respectively. The temporal offset of Lake Iznik’s record is even larger. Although timing and amplitude of climate changes and its impact on vegetation can differ from region to region, slight inaccuracies in the lower part of the current age-depth model for Lake Iznik are likely.

2.5.2 Pre-LGM and LGM: ca. 28.4–18.4 ka cal BP (LPAZ 7)

A steppe vegetation predominated in the Iznik area during the pre-LGM and LGM (Last Glacial Maximum, i.e., the period with maximal global ice volume dating back to 23–19 ka cal BP according to Yokoyama et al., 2000 and Tzedakis, 2007). The abundance of the arboreal species *Hippophaë rhamnoides* suggests a cool and dry steppe (Tarasov et al., 1998), which is supported by a very low vegetation productivity (low pollen concentration and influx; Fig. 2.4). In contrast to adjacent LPAZs, a significant increase in percentages of the herbaceous Tubuliflorae and Liguliflorae as typical open-land indicators (Litt et al., 2012) is evident. The vegetation composition and the extremely low vegetation productivity suggest that precipitation rates were very low, probably comparable with 100–300 mm annual precipitation of today’s Central Anatolian dwarf shrub steppe (Roberts and Wright, 1993; Fig. 2.3). Pollen influx values of all taxa are lower than in adjacent LPAZ, which indicates that high percentages are not a result of increased pollen amounts of the concerned taxa but result from statistical effects. The high AP ratio must therefore be interpreted with cautions. Nevertheless, some taxa like Tubuliflorae, Liguliflorae, *Hippophaë rhamnoides*, and *Pinus* were more abundant compared to other taxa. This could be explained as follows (1) they were not as much effected by the harsh conditions as other taxa, (2) these plants lived in special habitats where microclimatic conditions were more favorable, or (3) pollen grains were transported by long distance. Due to the low pollen production by the upland vegetation of the Iznik area during LPAZ 7, the proportion of long-distance transported pollen is much larger (especially for *Pinus*; van Zeist et al., 1975; Faegri and Iversen, 1989).

The geochemical and sedimentological results from Lake Iznik indicate a low lacustrine bioproductivity coupled to a low endogen carbonate production (low Ca/Ti ratios) as a result of lower summer temperatures during the LGM (Roeser et al., 2012; Fig. 2.5). The deposition of dropstones within a clay matrix suggests the occurrence of at least a partial ice cover of Lake Iznik (Roeser, 2014). Still, the water conditions allowed the occurrence of *Botryococcus* (Fig. 2.5), which has a wider ecological tolerance than *Pediastrum* and can also survive in very cold or nutrient poor waters (Jankovská and Komárek, 2000). Peaking values of the magnetic susceptibility are ascribed to the deposition of the Y2 tephra (Roeser et al., 2012; Fig. 2.5), which is related to the ca. 22 ka cal BP Cape Riva eruption of Santorini (Pichler and Friedrich, 1976; Eriksen et al., 1990). It is an important chronostratigraphic marker in the Eastern Mediterranean (Çağatay et al., 2015).

In general, most paleoclimate records and models of the Eastern Mediterranean agree on cold and arid conditions during the LGM (van Zeist and Bottema, 1988; Robinson et al., 2006; Tzedakis, 2007; Valsecchi et al., 2012 (Fig. 2.6); but also see Şenkul and Doğan (2013) for another conclusion). Likewise the pollen record from the southern Black Sea indicates colder and drier climatic conditions compared to today, although an increased moisture availability compared to MIS 3 allowed the expansion of woodland (Shumilovskikh et al., 2014; Fig. 2.6).

However, ambiguous data are present for the millennia prior to the LGM, including the detection of rapid climate events. Although many high-resolution Eastern Mediterranean pollen records generally document vegetation changes in response to DO events, DO-2 (23.3–22.9 ka cal BP; Rasmussen et al., 2014) is not registered by the majority of records (Fletcher et al., 2010 and references therein). Compared to other DO events, the amplitude of the δ^{18}O curve from North Greenland in response to DO-2 is in fact quite low (NGRIP members, 2004; Fig. 2.6). However, the Tenaghi Philippon pollen record indicates the spread of pines in response to DO-2 (Müller et al., 2011). A vegetation response to DO-2 is not visible in Lake Iznik's pollen record because the environmental advantages did probably not cross a critical threshold for tree growth in the eastern Marmara region (but also note the rather low temporal resolution of samples; Table 2.2). Likewise, there is no unambiguous evidence for a vegetation change in response to Heinrich Stadial 2 (26.5–24.3 ka cal BP; Sanchez Goñi and Harrison, 2010) in Lake Iznik's pollen record. Environmental changes related to this rapid climate event were documented in some Eastern Mediterranean records, e.g., from the northwestern Black Sea (Kwiecien et al., 2009) and the Dead Sea (Torfstein et al., 2013). However, other records, e.g., from the Tenaghi Philippon site (Tzedakis et al., 2004) and the southern Black Sea (Shumilovskikh et al., 2014; Fig. 2.6) do not indicate a vegetation response related to Heinrich Stadials. In areas where tree populations were already close to their climatic tolerance limit, differences between harsh Heinrich Stadials and other stadials might not be detected because even moderate stadial conditions could cross the ecological threshold for tree growth (Tzedakis et al., 2004). This explanation could also pertain for the catchment of Lake Iznik. Still, a higher sampling resolution might result in the detection of rapid climate changes of centennial scale during that time.

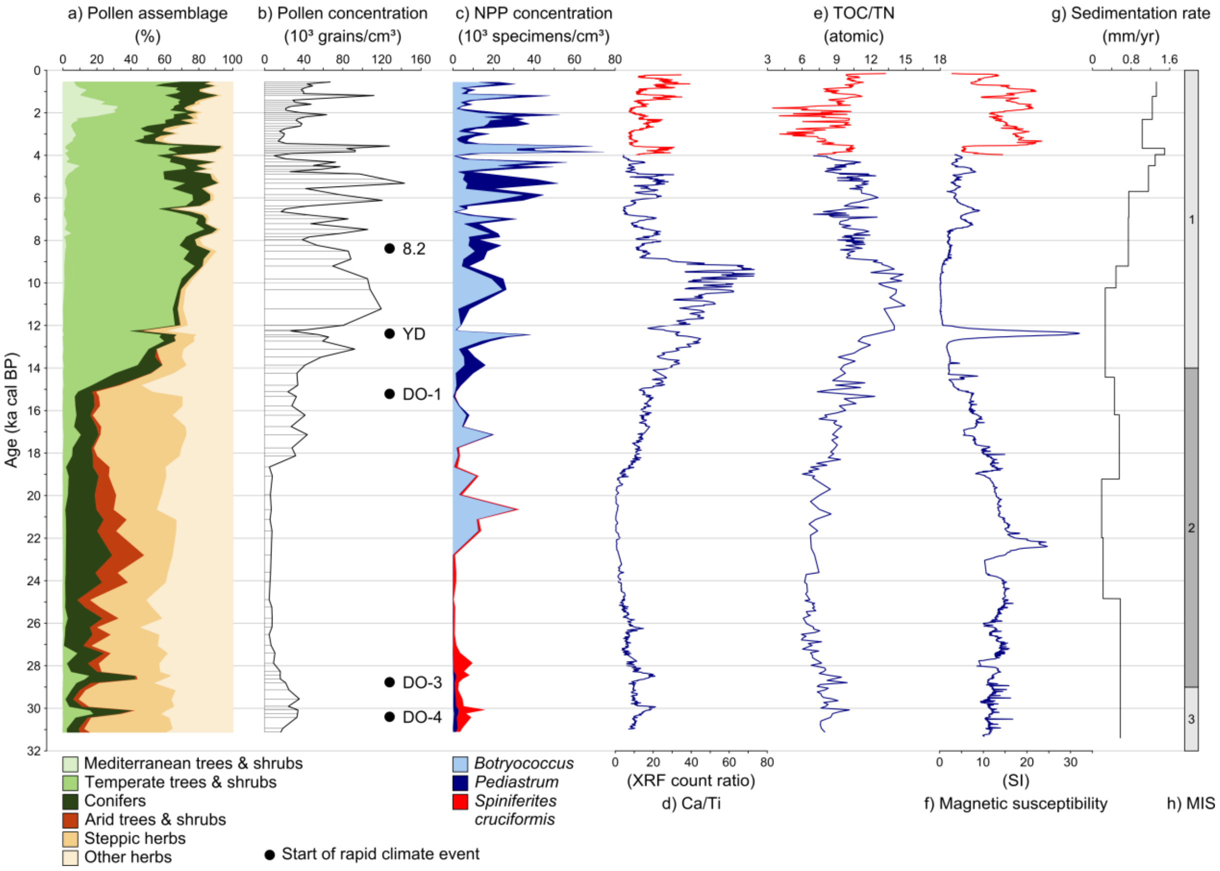


Figure 2.5: Comparison of different proxies inferred from Lake Iznik sediments: (a) pollen assemblage, (b) total pollen concentrations, (c) non-pollen palynomorph (NPP) concentrations, (d) calcium/titanium (Ca/Ti) ratios (represent the lake-wide endogen carbonate precipitation; relative changes between the red curve (Ülgen et al., 2012) and the blue curve (Roeser et al., 2012) are comparable), (e) total organic carbon/total nitrogen (TOC/TN) ratios (relate to catchment vegetation cover and are influenced by the distance to the shoreline; hence, differences between the red curve (Ülgen et al., 2012) and the blue curve (Roeser, 2014) most likely result from different coring locations), (f) magnetic susceptibility (relatable to the detrital input and the diagenetic remobilization of iron and sulfur; changes between the red curve (Ülgen et al., 2012) and the blue curve (Roeser et al., 2012) are most likely analytical artefacts), (g) sedimentation rates (Roeser et al., 2016), (h) marine isotope stages (MIS; Lisiecki and Raymo, 2005). Dots mark Dansgaard-Oeschger events (DO), the Younger Dryas (YD), and the 8.2 event.

2.5.3 Post-LGM: ca. 18.4–15 ka cal BP (LPAZ 6)

The onset of LPAZ 6 corresponds to the termination of the LGM and is marked by a ratio change of steppe components in Lake Iznik's pollen record: mainly *Artemisia* displaces Tubuliflorae, Liguliflorae, Brassicaceae, Caryophyllaceae, and *Hippophaë rhamnoides* (Fig. 2.4). The occurrence of *Ephedra*, a genus, which is associated with the desert biome (Prentice et al., 1996), points to seasonal moisture deficiencies. However, increasing pollen concentrations and decreasing open steppe indicators (especially Tubuliflorae and Liguliflorae) suggest a denser vegetation. The general higher plant productivity was supported by increased summer insolations (Berger, 1978; Berger et al., 2007; Fig. 2.6) implying higher temperatures and longer growing seasons. Moreover, pioneer trees of the Cupressaceae family (*Juniperus* and/or *Cupressus sempervirens*) and birch (*Betula*) formed open forests patches, which were accompanied by pines and successively also by deciduous oaks. The development of an open woodland with *Juniperus*, *Pinus*, *Betula*, and *Quercus* is typical for the pre-temperate phase of a glacial-interglacial cycle in southern Europe and corresponds to a climatic warming (Tzedakis, 2007).

Steadily increasing Ca/Ti ratios at Lake Iznik result from an increasing lacustrine bioproductivity in response to milder climatic conditions (Roeser et al., 2012; Fig. 2.5). The denser catchment vegetation contributes to an increased terrestrial proportion of accumulated organic matter, which is reflected by increasing TOC/TN ratios (Roeser, 2014; Fig. 2.5) and is supported by a decreasing magnetic susceptibility (Roeser et al., 2012; Fig. 2.5).

An ongoing dominance of steppe vegetation during the post-LGM is reflected in many Eastern Mediterranean records. Still, regional variations occurred: while eastern Anatolia was dominated by a cold semi-desert steppe with almost no arboreal taxa (Litt et al., 2009), more trees (primary pines) occurred in northern Turkey (van Zeist and Bottema, 1991; Shumilovskikh et al., 2012; Fig. 2.6), and the amount of arboreal pollen was even higher in the Aegean region (Kotthoff et al., 2008) and in Greece (Lawson et al., 2004; Müller et al., 2011). In contrast to our study, Kwiecien et al. (2009) and Valsecchi et al. (2012) proposed harsher climatic conditions during the post-LGM compared to the LGM for northwestern Turkey in response to Heinrich Stadial 1 (18–15.6 ka cal BP; Sanchez Goñi and Harrison, 2010). Valsecchi et al. (2012) suggested colder and/or drier conditions in the Marmara region due to increased pollen percentages of steppic plants and decreased percentages of temperate trees (Fig. 2.6).

2.5.4 Lateglacial: ca. 15–12.1 ka cal BP (LPAZ 5)

The onset of LPAZ 5 is characterized by shortly peaking values of Poaceae followed by an enormous increase of deciduous oaks and a peak of *Pinus* pollen amounts (Fig. 2.4). Simultaneously, steppe components like Chenopodiaceae decrease abruptly. The change in the vegetation composition suggests warmer and moister climatic conditions. A similar pattern was already found during DO-3 and DO-4 in Lake Iznik's pollen assemblage. Likewise, this vegetation change corresponds to DO-1, which can be used as a synonym for the Lateglacial Interstadial (Bølling-Allerød) and started ca. 14.6 ka cal BP according to the NGRIP record (Rasmussen et al., 2014). Pioneer forests of *Betula* and *Juniperus/Cupressus sempervirens* got successively replaced by temperate summer-green trees going along with a rapid forest expansion. However, pollen concentrations indicate that the forest expansion and the spread of oaks was somewhat slower than percentages may suggest. Therefore, the full development of the forests in the catchment of Lake Iznik did not take place before the early Holocene.

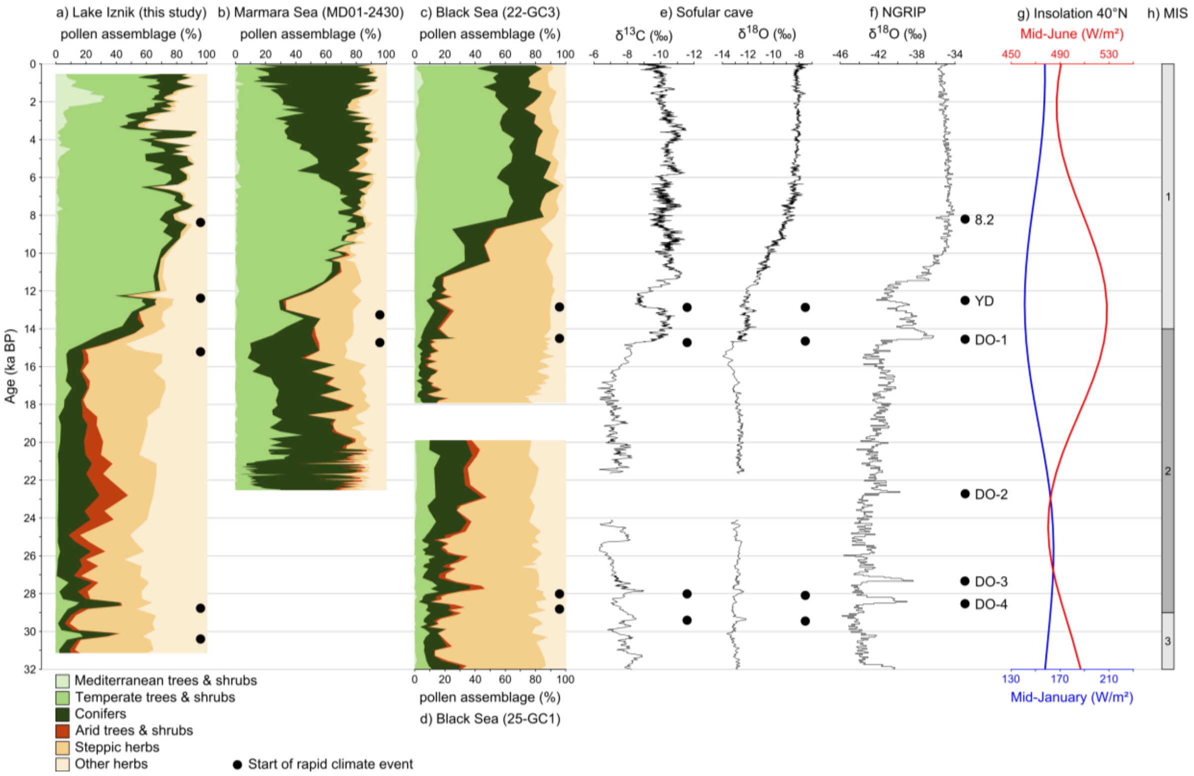


Figure 2.6: Comparison of pollen assemblages from (a) Lake Iznik (this study), (b) Marmara Sea, core MD01-2430 (Valsecchi et al., 2012), (c) Black Sea, core 22-GC3 (Shumilovskikh et al., 2012), and (d) Black Sea, core 25-GC1 (Shumilovskikh et al., 2014) with (e) isotope data from Sofular cave (Fleitmann et al., 2009), (f) isotope data from Greenland (NGRIP members, 2004), (g) mid-June and mid-January insolation (Berger, 1978; Berger et al., 2007), and (h) marine isotope stages (MIS; Lisiecki and Raymo, 2005). Dots mark Dansgaard-Oeschger events (DO), the Younger Dryas (YD), and the 8.2 event.

During LPAZ 5, two retreats in the forest expansion are noticeable. A peak of *Artemisia* together with a decrease of AP and a slowdown of the *Quercus* expansion indicate a weakening of favorable climatic conditions for tree growth and a short-term stagnation of forest expansion around ca. 13.3 ka cal BP. The period might correspond to a cooler sub-event during DO-1 (Rasmussen et al., 2014). The second forest retreat within LPAZ 5 (around ca. 12.3 ka cal BP) is much more pronounced. An abrupt decline of several trees and shrubs (with the exception of *Ephedra*), an expansion of mainly Chenopodiaceae and Poaceae, and a decrease of pollen concentrations mark a period of dryer and/or cooler climate in the catchment of Lake Iznik. This climate change is associated with the Younger Dryas (YD).

The rapid increase of deciduous oaks at ca. 15 ka cal BP coincides with a rapid rise of *Pediastrum* (Fig. 2.5), which indicates increasing lake water temperatures or a higher nutrient supply to the lake (Jankovská and Komárek, 2000). Increasing TOC/TN values might support a general higher biomass, although increasing proportions of terrestrial organic material in Lake Iznik can be related to phases of lower lake levels as indicated by independent proxies (Roeser, 2014; Fig. 2.5). The enhanced endogen carbonate production clearly outlines increasing summer temperatures (higher Ca/Ti ratios; Roeser et al., 2012; Fig. 2.5).

During DO-1, a short phase of lower algae concentrations (Fig. 2.5), lower Ca/Ti ratios (Roeser et al., 2012; Fig. 2.5), and lower TOC/TN ratios (Roeser, 2014; Fig. 2.5) also lead to the interpretation of a rapid cooling, which is expressed by the short-term stagnation of forest expansion. During the YD, the retreat of forests relates to lower summer temperatures (lowering Ca/Ti ratios) and colder water temperatures (low NPP concentrations). A 2 cm thick layer of coarse sediments possibly represents a timely coincident distal deposition of a mass movement. This coarser layer is overprinted by iron monosulfides expressed by a peak in the magnetic susceptibility (Roeser et al., 2012; Fig. 2.5). The YD is condensed in Lake Iznik's sediments due to low sedimentation rates. According to the well-dated NGRIP chronology (Rasmussen et al., 2014; NGRIP members, 2004; Fig. 2.6) and varve chronologies from Lake Van (Wick et al., 2003) and Europe (Litt et al., 2001), the YD phase lasted about 1100 to 1200 years.

The spread of deciduous oaks in response to the onset of DO-1 is a common pattern in the Eastern Mediterranean. It is registered in many pollen records from northwestern Turkey and Greece, e.g., from Tenaghi Philippon (Müller et al., 2011), Ioannina basin (Lawson et al., 2004), the Marmara Sea (Valsecchi et al., 2012; Fig. 2.6), and the southern Black Sea (Shumilovskikh et al., 2012; Fig. 2.6). In addition, rapidly increasing $\delta^{13}C$ values from Sofular Cave indicate the spread of trees and shrubs at the southern Black Sea coast since 14.6 ka cal BP (Fleitmann et al., 2009; Fig. 2.6). By contrast, the spread of deciduous oaks in other parts of the Near East started after the Pleistocene-Holocene boundary (Bottema, 1995). For example at Lake Van (eastern Turkey), a slow oak steppe-forest expansion suggests dry spring and summer conditions (Wick et al., 2003; Litt et al., 2009), and at the western Black Sea coast, a steppe vegetation dominated until the early Holocene (Atanassova, 2005).

The retreat of mesic forests and the spread of steppic vegetation is a typical expression of the Younger Dryas in the Marmara region (Mudie et al., 2002; Valsecchi et al., 2012; Fig. 2.6) and in general in the Eastern Mediterranean (Bottema, 1995; Rossignol-Strick, 1995). Also rapidly decreasing $\delta^{13}C$ values from Sofular Cave indicate the retreat of trees and shrubs at the southern Black Sea coast since 12.9 ka cal BP (Fleitmann et al., 2009; Fig. 2.6). In the pollen record from the southern Black Sea, the YD is less strongly expressed although a retreat of trees is still evident (Shumilovskikh et al., 2012; Fig. 2.6).

2.5.5 Early Holocene: ca. 12.1–9 ka cal BP (LPAZ 4)

The lower boundary of LPAZ 4 coincides with the Pleistocene-Holocene boundary, which was dated to 11.7 ka cal BP (e.g., Walker et al., 2008). The early Holocene of Lake Iznik's pollen record is characterized by constantly high percentages of *Quercus*, which shows that deciduous oaks were a major element of the landscape. Successively also other trees and shrubs followed. Main components (> 2 %) of the forest succession, which already started during the Lateglacial, were (1) deciduous *Quercus* together with an initial peak of *Pinus*, (2) *Alnus*, (3) *Ulmus*/*Zelkova* (elm/zelkova), (4) *Corylus* (hazel) and *Carpinus*/*Ostrya* (hornbeam), (5) *Abies*, (6) *Fagus* (beech). Constantly high pollen concentrations in LPAZ 4 point to a dense vegetation and a development from open woodland during DO-1 to dense forests during the early Holocene. As a result of the forest expansion, spores of the bracken fern (*Pteridium*) and Polypodiaceae, a family of polypod ferns, become constantly present. In contrast, all NAP components are very rare except for Poaceae and *Sanguisorba minor* type (*Sanguisorba minor* and/or *Sarcopoterium spinosum*), which reaches its highest percentages during LPAZ 4. The abrupt increase of *S. minor* type takes place simultaneously with the first consistence occurrence of *Pistacia* (pistachio) between ca. 11.2 and 12 ka cal BP. *Pistacia* is a poor pollen producer and known for its under-representation in sediments (Rossignol-Strick, 1995; Mudie et al., 2002; Lawson et al., 2004). Hence, low percentages (< 1.2 % at Lake Iznik) are still informative (Lawson et al., 2004). Furthermore, it indicates mild climatic conditions (Rossignol-Strick, 1995) with mean minimum temperatures of the coldest month above 5 °C (Prentice et al., 1996). Frosts, if present at all in the vicinity of Lake Iznik, were reduced in frequency. The warm temperatures went along with the high stand in summer insolation (Berger, 1978; Berger et al., 2007; Fig. 2.6). The spread of temperate and mesic trees together with the virtual absence of *Artemisia* and Chenopodiaceae also point to an increase of available moisture compared to glacial times.

During the early Holocene, the lake level of Lake Iznik was relatively low (Roeser et al., 2012), which resulted together with summer insolation maxima (Berger, 1978; Berger et al., 2007; Fig. 2.6) in overall highest Ca/Ti ratios (Roeser et al., 2012; Fig. 2.5). Also high amounts of terrestrial organic matter are documented in the sedimentary record (high TOC/TN ratios; Roeser, 2014; Fig. 2.5).

Similar to the rapid spread of forests in the Iznik area at the beginning of the Holocene, also $\delta^{13}C$ values from Sofular Cave decrease distinctly (Fleitmann et al., 2009; Fig. 2.6), which suggests an increase of effective moisture (Göktürk et al., 2011). In accordance to the Lake Iznik record, AP amounts from the Tenaghi Philippon record increase considerably (Müller et al., 2011). However, the pollen records from the southern Black Sea (Shumilovskikh et al., 2012; Fig. 2.6), the Aegean Sea (Kotthoff et al., 2008), and Lake Van (Litt et al., 2009) suggest a slower forest expansion.

The first consistent occurrence of the *Sanguisorba minor* pollen type and of *Pistacia* at the onset of the Holocene is a typical pattern of pollen records from the Eastern Mediterranean and can therefore be used as a stratigraphic marker (Rossignol-Strick, 1995; Kotthoff et al., 2008; Valsecchi et al., 2012). Our study confirms the stratigraphic character of these pollen types.

2.5.6 Mid-Holocene: ca. 9–3.5 ka cal BP (LPAZ 3)

The mid-Holocene in the Iznik area was characterized by a general continuing of temperate deciduous forest and mild and warm climatic conditions (Figs. 2.4, 2.7). However, the amount of conifers raised. The increased frequency of *Abies* and *Fagus*, which started already at ca. 9.8 ka cal BP but amplifies in LPAZ 3, suggests slightly moister climatic conditions compared to the early Holocene. The abundance of *Abies* was probably even higher than suggested by the pollen percentages because *Abies* is known for its under-representation in pollen diagrams (van Zeist et al., 1975). Firs and beeches probably grew in the mountain areas surrounding Lake Iznik.

Several phases of decreased forest cover and simultaneous drops of pollen concentrations and influxes are visible in LPAZ 3. Potential climatic triggers causing these vegetation changes are especially probable for periods when no or few anthropogenic indicator taxa (cultivated plants and non-cultivated plants, which benefit from anthropogenic influences; e.g., Behre, 1990; Bottema and Woldring, 1990; Fig. 2.7) appeared simultaneously. The most pronounced of these periods are centered at ca. 8, ca. 6.5, and ca. 4.1 ka cal BP. However, the determination of the exact duration of those changes is challenging because possible rapid fluctuations of the sedimentation rate would potentially affect the duration of recorded events and eventually also bias the pollen influx. Such expected rapid fluctuations are generally not accounted for by age-depth models, which reflect rather the average sedimentation. The high synchronicity of pollen concentrations and NPP concentrations support this assumption (Fig. 2.5).

Several anthropogenic indicator taxa appear in LPAZ 3 (Fig. 2.7). For instance, a small peak of *Olea europaea* percentages is visible around 7.7 ka cal BP. Still, this is not unambiguous evidence for olive cultivation, because olives are natural components of the Mediterranean vegetation (Zohary, 1973), the increase is just represented by a single sample and therefore needs further investigation, and olive cultivation in the Near East started most likely about a millennium later (Weiss, 2015) and is therefore very unlikely (cf. Sadori and Narcisi, 2001). Although also other anthropogenic indicator taxa can occur naturally in the Marmara region (Zohary, 1973), evidence for human activities consolidates when anthropogenic indicator taxa show higher abundances, several anthropogenic indicator taxa occur simultaneously, and natural forests retreat contemporaneously. Likewise, the first unambiguous evidence for human-induced changes of the vegetation documented in Lake Iznik's pollen record starts at ca. 4.8 ka cal BP. Olives and cereals were most likely cultivated. Although Cerealia type percentages only slightly increase, those changes are still informative due to their under-representation in pollen diagrams (van Zeist et al., 1975; Faegri and Iversen, 1989). The increase of the *Plantago lanceolata* pollen type may point to area disturbance or grazing (van Zeist et al., 1975; Behre, 1990). The simultaneous occurrence of *Vaccinium* type pollen, which probably originated from *Erica*, indicates the development of macchia vegetation (Kürschner et al., 1997).

Moister conditions since ca. 9 ka cal BP are also suggested by geochemical analysis from Lake Iznik (Roeser et al., 2012; Roeser, 2014). The abrupt retreat in carbonate accumulation indicates a lake level rise that lasted circa 500 years (decreasing Ca/Ti ratios; Roeser et al., 2012; Fig. 2.5).

Similar to the Lake Iznik record, also other studies document a moisture rise during the mid-Holocene. An increase in humidity since ca. 9.6 ka cal BP was inferred from the Sofular cave record based on high stalagmite growth rates and low $(^{234}U\ /\ ^{238}U)_o$ ratios (Göktürk et al., 2011), while the pollen record from the southern Black Sea indicates moister and warmer climatic conditions since ca. 8.3 ka cal BP due to a rapid spread of temperate forest (Shumilovskikh et al., 2012; Fig. 2.6).

The 8.2 ka cold event is the most prominent rapid climate change (RCC) at northern high latitudes during the Holocene (Johnsen et al., 2001; NGRIP members, 2004; Fig. 2.6). Phases with reduced precipitation were described in several Eastern Mediterranean records, but they often lasted longer compared to the sharp and short 8.2 ka event at northern high latitudes (e.g., Staubwasser and Weiss, 2006; Kotthoff et al., 2008; Weninger et al., 2009; Göktürk et al., 2011). The vegetation change in the Iznik area around 8 ka cal BP might also correspond to the 8.2 event. However, the synchronous appearance of several archaeological settlements (Bottema et al., 2001; Gerritsen et al., 2013a, b; Fig. 2.7; see Fig. 2.8 for the locations) makes it difficult to separate anthropogenic and climatic influences on the vegetation. Also Bottema et al. (2001) considered human impacts for a contemporaneous destruction of forests in the Yenişehir area, south of Lake Iznik.

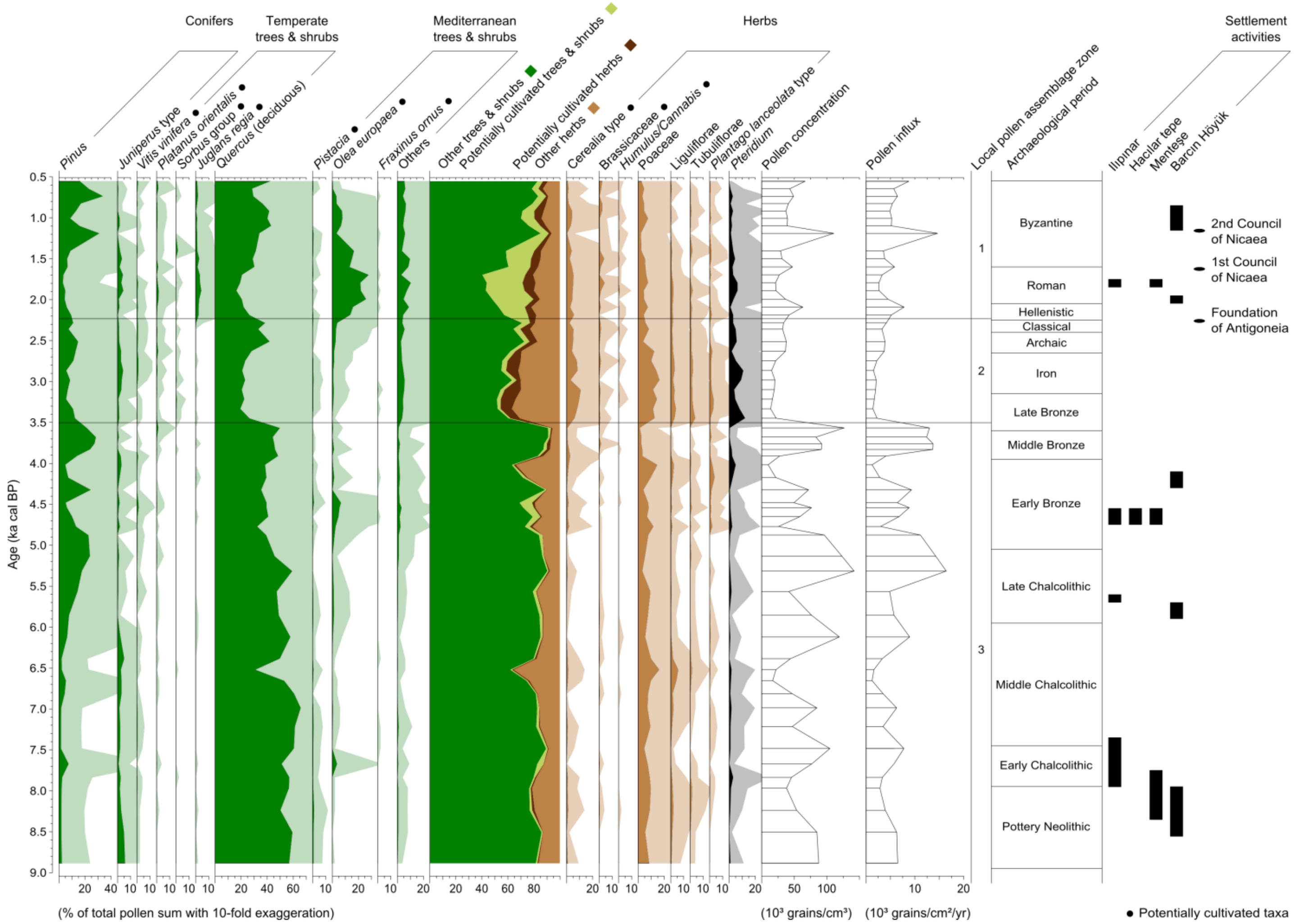


Figure 2.7: Pollen diagram of the last 9 ka cal BP inferred from Lake Iznik sediments with archaeological periods (Eastwood et al., 1998; Sagona and Zimansky, 2009), settlement activities of archaeological settlements in the vicinity of Lake Iznik (Ilıpınar, Hacılar tepe, and Menteşe after Bottema et al. (2001) and Barcın Höyük after Gerritsen et al. (2013a, b); see Fig 2.8. for the locations), the foundation of Antigoneia (later Iznik; Abbasoğlu and Delemen, 2003), and the two ecumenical councils of Nicaea (later Iznik; Şahin, 2003).

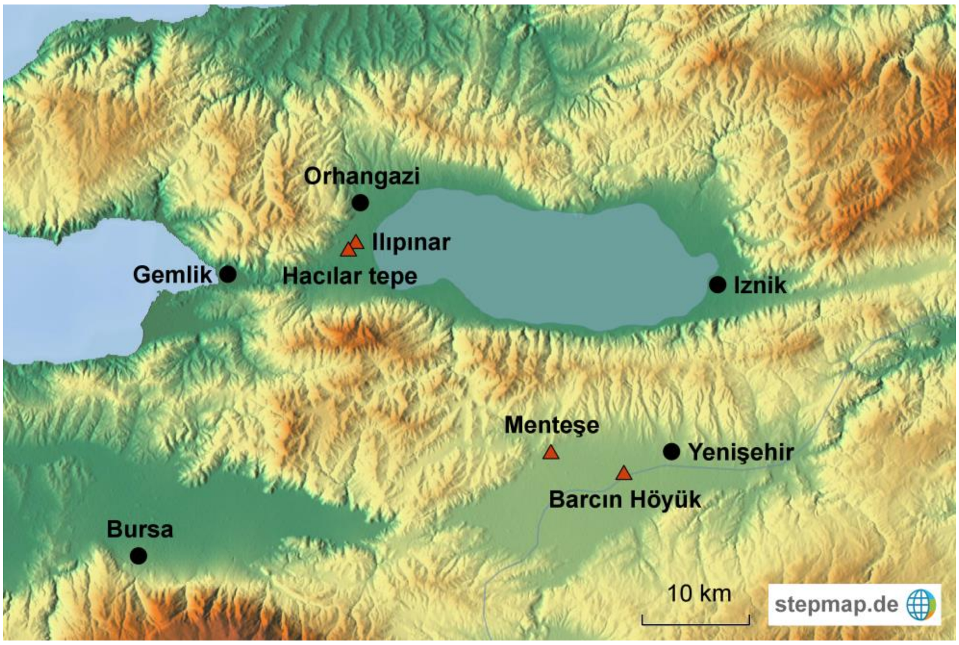


Figure 2.8: Archaeological settlements (red triangles) in the vicinity of Lake Iznik.

According to Roberts et al. (2011), a dry phase took place in the Eastern Mediterranean ca. 6600 years ago. The forest retreat in the Iznik area around 6.5 ka cal BP might correspond to this climate event (note that the age-depth model during this phase is based on radiocarbon dates subjected to reservoir effects; Roeser et al., 2014). However, the magnitude of the vegetation change is large, which leads to the assumption of (additional) anthropogenic influences. Although anthropogenic indicator species are rare and there is no evidence for settlements near Lake Iznik at that time (Fig. 2.7), the subsequent spread of pines might indicate a permanent opening of forests by humans. Pines can have a pioneer role in anthropogenic influenced landscapes, and they quickly distribute in abandoned areas (Litt et al., 2012). Though, a similar spreading pattern of *Pinus* is also found in the pollen record from the Marmara Sea (Valsecchi et al., 2012; Fig. 2.6; note that pines are often considerably over-represented in marine pollen assemblages) and therefore counters against a local vegetation development.

The unambiguous evidence for human-induced vegetation changes in the Iznik area at ca. 4.8 ka cal BP is in accordance with documented settlement activities in the vicinity of Lake Iznik (Bottema et al., 2001; Gerritsen et al., 2013a, b; Fig. 2.7). Also Bottema et al. (2001) postulated the relationship of these settlements and a deforestation in the Yenişehir area.

According to Mayewski et al. (2004), there is evidence for an RCC at 4.2–3.8 ka cal BP in some paleo records on global scale (the so-called 4.2 ka event). A pronounced aridity prevailed in the Eastern Mediterranean around 4.2 ka cal BP, although timing and magnitude of changes varies considerably among different records (Bar-Matthews and Ayalon, 2011; Finné et al., 2011 and references therein; Masi et al., 2013). The forest retreat around ca. 4.1 ka cal BP in the Iznik area might also be associated with this dry period. However, an extensive cultural network across Anatolia was already established by the end of the Early Bronze Age (Sagona and Zimansky, 2009). Therefore, persistent anthropogenic influences on the vegetation are also possible.

2.5.7 Late Bronze Age to Classical Period: ca. 3.5–2.2 ka cal BP (LPAZ 2)

During the Late Bronze Age, at ca. 3.5 ka cal BP, an enormous change in the vegetation took place in the catchment of Lake Iznik (Fig. 2.7). At least since that time, the vegetation development was overprinted by human impacts and the detection of climate influences on the vegetation is hardly possible. Natural forests got cleared, from which mainly deciduous oaks and pines were affected. People probably cleared the low-altitude forests, where *Quercus* and *Pinus* were most likely common as they are today (Atalay et al., 2014). Cereal cropping was an important form of land use, while fruit cultivation played a minor role. Open land vegetation like Asteraceae (mainly Liguliflorae) and grasses benefited from the retreat of forests and from agricultural use including grazing (Bottema and Woldring, 1990; Florenzano et al., 2015). But also Mediterranean taxa like Ericaceae (*Vaccinium* type) and evergreen oaks became rapidly more abundant. The abundance of the *Plantago lanceolata* pollen type and the rapid increase of *Pteridium* indicate a stronger human activity in the catchment of Lake Iznik (van Zeist et al., 1975; Bottema and Woldring, 1990). *Platanus orientalis* (oriental plane) pollen grains are continuously present since ca. 3.9 ka cal BP. The oriental plane is a natural component of the local vegetation and is especially abundant in riparian habitats (van Zeist et al., 1975). It was probably planted to provide shade like it is still done today in Anatolian villages (Eastwood et al., 1998).

A conspicuous palynologically identifiable settlement period firstly described from southwestern Turkey, the Beyşehir occupation phase (BOP), started at ca. 3.4 ka cal BP (van Zeist et al., 1975; Eastwood et al., 1998). Correlating phases in pollen records were subsequently observed in greater parts of Turkey and in the Aegean region (Eastwood et al., 1998; Bottema, 2000). The similar timing of vegetation changes in the Iznik pollen record prompts to a correlation to this phase. Although the assemblage and abundance of cultivated taxa during the BOP varies among the different records (Eastwood et al., 1998; Bottema, 2000), the secondary role of arboriculture in the Iznik area depicts a major difference compared to other records. It is still not fully understood which culture accounted for the observed vegetation changes during the BOP (Eastwood et al., 1998). The Late Bronze Age was the time of the Hittites, who dominated large parts of Anatolia. However, no Hittite sites are known from northwestern Turkey including the Iznik area. The Iron Age in northwestern Turkey was politically shaped by the Kingdom of Phrygia, which was bordered by the Assyrian Empire to its southeast and the Kingdom of Urartu to its northeast (Sagona and Zimansky, 2009).

During the Archaic and Classical Period (ca. 2.6–2.2 ka cal BP) deciduous oaks recovered to a certain extent and open land vegetation as well as *Plantago lanceolata* type became less abundant. Such a pattern may indicate a different form of land use in certain areas. The re-spread of trees might indicate that logging, herding, or intentional burning was reduced (Bottema et al., 2001). Still, cereal cropping continued, which suggests a continuity of colonization and agriculture. At the beginning of the Archaic Period, the dynasty of Lydia displaced the Kingdom of Phrygia (Sagona and Zimansky, 2009). This change in culture and politics coincides with the described change in Lake Iznik’s pollen assemblage.

2.5.8 Hellenistic Period to Byzantine Period: ca. 2.2–0.6 ka cal BP (LPAZ 1)

The uppermost LPAZ is characterized by an abrupt increase of *Olea europaea* and *Juglans regia*, which suggests that walnuts and especially olives were widely cultivated (Fig. 2.7). While cereal cropping continued like in previous phases, the arboriculture became an important additional agriculture form. Mainly deciduous oaks and pines were cut again. During the Hellenistic Period, the Iznik area was incorporated to the Bithynian Kingdom. Antigoneia (later Nicaea and finally Iznik) was founded at the eastern shore of Lake Iznik (Abbasoğlu and Delemen, 2003).

The maximal percentages of *Olea europaea* and minimal percentages of natural forest elements are found during the Roman Period (ca. 2.05–1.65 ka cal BP). Apparently, the general anthropogenic influence on the vegetation increased (higher amounts of *Pteridium* and lower pollen concentrations probably due to increased erosion), and olive cultivation expanded. In 74 BC (2024 BP), the Iznik area became incorporated into the Roman Empire. Iznik developed very quickly (Abbasoğlu and Delemen, 2003) and was one of the largest cities in the region. Furthermore, the city became famous for hosting a large ecumenical council in 325 AD (1625 BP; Şahin, 2003). Settlement activities are also described for other archaeological sites close to Lake Iznik (Bottema et al., 2001; Gerritsen et al., 2013a, b; Fig. 2.7).

Olea europaea pollen percentages retreat at ca. 1.3 ka cal BP, which indicates that many olive orchards were abandoned. Percentages of other human indicator taxa decrease as well. Concurrently *Pinus* pollen rise significantly, which suggests the recolonization of abandoned agricultural land by pine forests. Pines probably also benefited from human-induced soil degradation (Roberts, 1990). The AP ratio and pollen concentration reach magnitudes comparable to the mid-Holocene, which indicates that the vegetation still had the ability to recover despite the preceding disturbances. This was also the case at other forested sites in the Eastern Mediterranean (e.g., Ionnania, northwestern Greece). In contrast, in some drier areas (e.g., Central Anatolia) the anthropogenic forest loss was irreversible (Roberts et al., 2011 and references therein).

During the Byzantine Period (1.15–0.8 ka cal BP), a repeated foray of humans is documented in Lake Iznik’s pollen record. The cultivation of olives and cereals increased once more, although it did not reach dimensions comparable to earlier times. Pines retreated quickly and strongly again, while deciduous oaks were not affected by the probable forest clearing. Simultaneously, in 787 AD (1163 BP), a second famous ecumenical council took place in Iznik (Şahin, 2003).

The uppermost part of LPAZ 1 shows a less intense human exploitation on the vegetation. The forest recovered and anthropogenic indicator taxa were not very abundant. This study covers the time period until ca. 0.55 ka cal BP (1400 AD) and therefore does not include the last centuries.

2.6 Conclusions

1. This study reveals the vegetation and climate history of the last ca. 31 000 years inferred from lacustrine sediments of Lake Iznik, the largest lake in the Marmara region. Special emphasis is given to climate variability based on signal analysis of biotic proxies such as pollen.

2. A steppe with dwarf-shrubs, grasses, and other herbs dominated during glacial/stadial conditions indicating dry and cold climatic conditions. In particular between ca. 28.4 and 18.4 ka cal BP (MIS 2), very low pollen concentrations and influx rates (pollen accumulation) suggest a very sparse vegetation cover and a very harsh climate. Therefore, pollen percentages are considerably biased amongst others by long distance transported pollen like *Pinus* pollen.

3. Forest-steppe with scattered stands of trees and shrubs (mainly deciduous oaks and pines) developed during interstadial conditions associated with Dansgaard-Oeschger events 4 and 3.

4. Deciduous oaks spread rapidly since the Lateglacial, which indicates warmer and moister climatic conditions. They were successively accompanied by other deciduous, coniferous, and evergreen trees. The spread of forests suffered a setback during the Younger Dryas caused by cold and/or dry climatic conditions.

5. Subsequent forest retreats were either caused by climatic anomalies (particularly the 8.2 event), human influences, or a combination of both. However, a clear anthropogenic impact on the vegetation is document in Lake Iznik's pollen record since ca. 4.8 ka cal BP. The vegetation development was overprinted by human impacts at least since the Late Bronze Age, which makes it hardly possible to detect climate-induced vegetation changes.

6. Cereals, olives, and walnuts were among the most important cultivars in the Iznik area. Oriental planes were probably planted to provide shade in settlements. Grape vines, manna-ashes, stone fruit trees of the rose family (*Sorbus* group), pistachios, cruciferous crops (Brassicaceae), hop and/or hemp (*Humulus*/*Cannabis*) may have been cultivated.

7. Phases of different agricultural use alternated with phases of forest regeneration. A strong coincidence of vegetation changes and the regional archaeological history becomes apparent. Rapid fluctuations in pollen concentrations since the mid-Holocene might indicate rapid changes of Lake Iznik's sedimentation rates caused by catchment erosion.

2.7 Data availability

The complete pollen and NPP dataset is available online at doi:10.1594/PANGAEA.858056.

The Supplement related to this article is available online at doi:10.5194/cp-12-575-2016-supplement.

2.8 Acknowledgements

A part of this work is based on the unpublished master theses of Andrea Miebach and Phoebe Niestrath carried out at the Steinmann Institute at the University of Bonn under the supervision of Thomas Litt and Jens Mutke, and Thomas Litt and Georg Heumann, respectively. We thank the teams of the coring campaigns at Lake Iznik in 2005 and 2009. We acknowledge Karen Schmeling for her technical support. We are very grateful for useful discussions with Nadine Pickarski and her improvements of the manuscript. Furthermore, we thank Verushka Valsecchi, Maria Fernanda Sanchez Goñi, and Umut Barış Ülgen for providing pollen and geochemical data. We acknowledge Fabienne Marret-Davies for her help to identify dinoflagellate cysts. This project is affiliated to the CRC 806 "Our way to Europe". We thank the German Science Foundation (DFG) for funding this project. We also thank Laura Sadori and an anonymous referee for reviewing this manuscript and Dominik Fleitmann for editorial handling.

Edited by: D. Fleitmann

2.9 References

Abbasoğlu, H. and Delemen, İ.: Remains from Acient Nicaea, in: İznik Throughout History, edited by: Akbaygil, I., İnalcık, H., and Aslanapa, O., Türkiye İş Bankası, Istanbul, 189–197, 2003.

Akbulak, C.: Human and Economic Geographical Investigation of Iznik Basin, Eurasia Ethnography Foundation Publications, Ankara, 2009.

Allen, J. R. M.,Watts,W. A., McGee, E., and Huntley, B.: Holocene environmental variability – the record from Lago Grande di Monticchio, Italy, Quatern. Int., 88, 69–80, doi:10.1016/S1040-6182(01)00074-X, 2002.

Alpar, B., Öztürk, K., Adatepe, F., Demirel, S., and Balkıs, N.: Sparker in lakes; reflection data from Lake Iznik, Turk. J. Mar. Sci., 9, 195–206, 2003.

Atalay, I., Efe, R., and Öztürk, M.: Ecology and Classification of Forests in Turkey, Procedia – Social and Behavioral Sci., 120, 788–805, doi:10.1016/j.sbspro.2014.02.163, 2014.

Atanassova, J.: Palaeoecological setting of the western Black Sea area during the last 15000 years, Holocene, 15, 576–584, doi:10.1191/0959683605hl832rp, 2005.

Bar-Matthews, M. and Ayalon, A.: Mid-Holocene climate variations revealed by high-resolution speleothem records from Soreq Cave, Israel and their correlation with cultural changes, Holocene, 21, 163–171, doi:10.1177/0959683610384165, 2011.

Behre, K.-E.: Some reflections on anthropogenic indicators and the record of prehistoric occupation phases in pollen diagrams from the Near East, in: Man's Role in the Shaping of the Eastern Mediterranean Landscape, edited by: Bottema, S., Entjes-Nieborg, G., and van Zeist, W., Balkema, Rotterdam, 219–230, 1990.

Benazzi, S., Douka, K., Fornai, C., Bauer, C. C., Kullmer, O., Svoboda, J., Pap, I., Mallegni, F., Bayle, P., Coquerelle, M., Condemi, S., Ronchitelli, A., Harvati, K., and Weber, G. W.: Early dispersal of modern humans in Europe and implications for Neanderthal behaviour, Nature, 479, 525–528, doi:10.1038/nature10617, 2011.

Berger, A.: Long-term variations of daily insolation and Quaternary climate changes, J. Atmos. Sci., 35, 2362–2367, doi:10.1175/1520-0469(1978)035<2362:LTVODI>2.0.CO;2, 1978.

Berger, A., Loutre, M. F., Kaspar, F., and Lorenz, S. J.: Insolation during interglacial, in: The Climate of Past Interglacials. Developments in Quaternary Sciences, edited by: Sirocko, F., Claussen, M., Sanchez Goni, M. F., and Litt, T., Elsevier, Amsterdam, 13–27, 2007.

Beug, H.-J.: Leitfaden der Pollenbestimmung fur Mitteleuropa und angrenzende Gebiete, Verlag Dr. Friedrich Pfeil, München, 2004.

Bond, G., Heinrich, H., Broecker, W., Labeyrie, L., Mcmanus, J., Andrews, J., Huon, S., Jantschik, R., Clasen, S., Simet, C., Tedesco, K., Klas, M., Bonani, G., and Ivy, S.: Evidence for Massive Discharges of Icebergs into the North-Atlantic Ocean during the Last Glacial Period, Nature, 360, 245–249, doi:10.1038/360245a0, 1992.

Bottema, S.: The Younger Dryas in the Eastern Mediterranean, Quaternary Sci. Rev., 14, 883–891, doi:10.1016/0277- 3791(95)00069-0, 1995.

Bottema, S.: The Holocene history of walnut, sweet-chestnut, manna-ash and plane tree in the Eastern Mediterranean, Pallas, 52, 35–59, 2000.

Bottema, S. and Woldring, H.: Anthropogenic indicators in pollen diagrams of the Eastern Mediterranean, in: Man’s Role in the Shaping of the Eastern Mediterranean Landscape, edited by: Bottema, S., Entjes-Nieborg, G., and van Zeist, W., Balkema, Rotterdam, 231–264, 1990.

Bottema, S., Woldring, H., and Kayan, I.: The Late Quarternary Vegetation History of Western Turkey, in: The Ilipinar Excavations II, edited by: Roodenberg, J. J. and Thissen, L. C., Nederlands Instituut voor het Nabije Oosten, Leiden, 327–354, 2001.

Çağatay, M. N., Wulf, S., Sancar, U., Ozmaral, A., Vidal, L., Henry, P., Appelt, O., and Gasperini, L.: The tephra record from the Sea of Marmara for the last ca. 70 ka and its palaeoceanographic implications, Mar. Geol., 361, 96–110, doi:10.1016/j.margeo.2015.01.005, 2015.

Chester, P. I. and Raine, J. I.: Pollen and spore keys for Quaternary deposits in the northern Pindos Mountains, Greece, Grana, 40, 299–387, doi:10.1080/00173130152987535, 2001.

Dansgaard, W., Clausen, H. B., Gundestrup, N., Hammer, C. U., Johnsen, S. F., Kristinsdottir, P. M., and Reeh, N.: A new Greenland deep ice core, Science, 218, 1273–1277, doi:10.1126/science.218.4579.1273, 1982.

Eastwood, W. J., Roberts, N., and Lamb, H. F.: Palaeoecological and Archaeological Evidence for Human Occupance in Southwest Turkey: The Beyşehir Occupation Phase, Anatolian Studies, 48, 69–86, doi:10.2307/3643048, 1998.

Eriksen, U., Friedrich, W. L., Buchardt, B., Tauber, H., and Thomsen, M. S.: The Stronghyle Caldera: Geological, palaeontological and stable isotope evidence from radiocarbon dated stromatolites from Santorini, in: Thera and the Aegean World III, Proceedings of the Third International Congress, Santorini, Greece, 1989, vol. 2., edited by: Hardy, D. A., Keller, J., Galanopoulos, V. P., Flemming, N. C., and Druitt, T. H., Thera Foundation, London, 139–150, 1990.

Faegri, K. and Iversen, J.: Textbook of Pollen Analysis, 4 Edn., John Wiley & Sons, Chichester, New York, Brisbane, Toronto, Singapore, 1989.

Finne, M., Holmgren, K., Sundqvist, H. S., Weiberg, E., and Lindblom, M.: Climate in the eastern Mediterranean, and adjacent regions, during the past 6000 years. A review, J. Archaeol. Sci., 38, 3153–3173, doi:10.1016/j.jas.2011.05.007, 2011.

Fleitmann, D., Cheng, H., Badertscher, S., Edwards, R. L., Mudelsee, M., Gokturk, O. M., Fankhauser, A., Pickering, R., Raible, C. C., Matter, A., Kramers, J., and Tuysuz, O.: Timing and climatic impact of Greenland interstadials recorded in stalagmites from northern Turkey, Geophys. Res. Lett., 36, L19707, doi:10.1029/2009gl040050, 2009.

Fletcher, W. J., Sánchez Goñi, M. F., Allen, J. R. M., Cheddadi, R., Combourieu-Nebout, N., Huntley, B., Lawson, I., Londeix, L., Magri, D., Margari, V., Müller, U. C., Naughton, F., Novenko, E., Roucoux, K., and Tzedakis, P. C.: Millennial-scale variability during the last glacial in vegetation records from Europe, Quaternary Sci. Rev., 29, 2839–2864, doi:10.1016/j.jas.2011.05.007, 2010.

Florenzano, A., Marignani, M., Rosati, L., Fascetti, S., and Mercuri, A. M.: Are Cichorieae an indicator of open habitats and pastoralism in current and past vegetation studies?, Plant Biosyst., 149, 154–165, doi:10.1080/11263504.2014.998311, 2015.

Franz, S. O., Schwark, L., Brüchmann, C., Scharf, B., Klingel, R., Van Alstine, J. D., Çagatay, N., and Ülgen, U. B.: Results from a multi-disciplinary sedimentary pilot study of tectonic Lake Iznik (NW Turkey) – geochemistry and paleolimnology of the recent past, J. Paleolimnol., 35, 715–736, doi:10.1007/s10933-005-5015-3, 2006.

Gerritsen, F., Fokke, A., Özbal, R., and Thissen, L. C.: The Earliest Neolithic Levels at Barcin Höyük, Northwestern Turkey, Anatolica, 39, 53–92, doi:10.2143/ANA.39.0.2990784, 2013a.

Gerritsen, F., Özbal, R., Thissen, L., Özdoğan, M., Başgelen, N., and Kuniholm, P.: Barcın Höyük: the beginnings of farming in the Marmara region, in: The Neolithic in Turkey: New Excavations and New Research. Vol. 5 Northwestern Turkey and Istanbul, edited by: Özdoğan, M., Başgelen, N., and Kuniholm, P., Archaeology and Art Publications, Istanbul, 93–112, 2013b.

Göktürk, O. M., Fleitmann, D., Badertscher, S., Cheng, H., Edwards, R. L., Leuenberger, M., Fankhauser, A., Tüysüz, O., and Kramers, J.: Climate on the southern Black Sea coast during the Holocene: implications from the Sofular Cave record, Quaternary Sci. Rev., 30, 2433–2445, doi:10.1016/j.quascirev.2011.05.007, 2011.

Grimm, E. C.: CONISS: a FORTRAN 77 program for stratigraphically constrained cluster analysis by the method of incremental sum of squares, Comput. Geosci., 13, 13–35, doi:10.1016/0098-3004(87)90022-7, 1987.

Heinrich, H.: Origin and consequences of cyclic ice rafting in the Northeast Atlantic Ocean during the past 130,000 years, Quaternary Res., 29, 142–152, doi:10.1016/0033-5894(88)90057-9, 1988.

Hemming, S. R.: Heinrich events: Massive late Pleistocene detritus layers of the North Atlantic and their global climate imprint, Rev. Geophys., 42, RG1005, doi:10.1029/2003rg000128, 2004.

Higham, T., Compton, T., Stringer, C., Jacobi, R., Shapiro, B., Trinkaus, E., Chandler, B., Groning, F., Collins, C., Hillson, S., O'Higgins, P., FitzGerald, C., and Fagan, M.: The earliest evidence for anatomically modern humans in northwestern Europe, Nature, 479, 521–524, doi:10.1038/nature10484, 2011.

Jankovská, V. and Komárek, J.: Indicative value of Pediastrum and other coccal green algae in palaeoecology, Folia Geobot., 35, 59–82, doi:10.1007/BF02803087, 2000.

Johnsen, S. J., Dahl-Jensen, D., Gundestrup, N., Steffensen, J. P., Clausen, H. B., Miller, H., Masson-Delmotte, V., Sveinbjörnsdottir, A. E., and White, J.: Oxygen isotope and palaeotemperature records from six Greenland ice-core stations: Camp Century, Dye-3, GRIP, GISP2, Renland and NorthGRIP, J. Quaternary Sci., 16, 299–307, doi:10.1002/jqs.622, 2001.

Köppen, W.: Versuch einer Klassifikation der Klimate, vorzugsweise nach ihren Beziehungen zur Pflanzenwelt, Geogr. Z., 6, 593–611, 1900.

Kotthoff, U., Müller, U. C., Pross, J., Schmiedl, G., Lawson, I. T., van de Schootbrugge, B., and Schulz, H.: Lateglacial and Holocene vegetation dynamics in the Aegean region: an integrated view based on pollen data from marine and terrestrial archives, Holocene, 18, 1019–1032, doi:10.1177/0959683608095573, 2008.

Kouli, K., Brinkhuis, H., and Dale, B.: Spiniferites cruciformis: a fresh water dinoflagellate cyst?, Rev. Palaeobot. Palyno., 113, 273–286, doi:10.1016/S0034-6667(00)00064-6, 2001.

Kürschner, H., Raus, T., and Venter, J.: Pflanzen der Türkei, 2 Edn., Quelle & Meyer, Wiesbaden, 1997.

Kwiecien, O., Arz, H. W., Lamy, F., Plessen, B., Bahr, A., and Haug, G. H.: North Atlantic control on precipitation pattern in the eastern Mediterranean/Black Sea region during the last glacial, Quaternary Res., 71, 375–384, doi:10.1016/j.yqres.2008.12.004, 2009.

Lawson, I., Frogley, M., Bryant, C., Preece, R., and Tzedakis, P.: The Lateglacial and Holocene environmental history of the Ioannina basin, north-west Greece, Quaternary Sci. Rev., 23, 1599–1625, doi:10.1016/j.quascirev.2004.02.003, 2004.

Le Houèrou, H. N.: Impacts of man and his animals on Mediterranean vegetation, in: Mediterranean type shrublands, edited by: Di Castri, F., Goodall, D. W., and Specht, R. L., Elsevier, Amsterdam, 523–535, 1981.

Lisiecki, L. E. and Raymo, M. E.: A Pliocene-Pleistocene stack of 57 globally distributed benthic δ^{18}O records, Paleoceanography, 20, PA1003, doi:10.1029/2004PA001071, 2005.

Litt, T., Brauer, A., Goslar, T., Merkt, J., Bałaga, K., Müller, H., Ralska-Jasiewiczowa, M., Stebich, M., and Negendank, J. F. W.: Correlation and synchronisation of Lateglacial continental sequences in northern central Europe based on annually laminated lacustrine sediments, Quaternary Sci. Rev., 20, 1233–1249, doi:10.1016/S0277-3791(00)00149-9, 2001.

Litt, T., Krastel, S., Sturm, M., Kipfer, R., Örcen, S., Heumann, G., Franz, S. O., Ülgen, U. B., and Niessen, F.: ’PALEOVAN’, International Continental Scientific Drilling Program (ICDP): site survey results and perspectives, Quaternary Sci. Rev., 28, 1555–1567, doi:10.1016/j.quascirev.2009.03.002, 2009.

Litt, T., Ohlwein, C., Neumann, F. H., Hense, A., and Stein, M.: Holocene climate variability in the Levant from the Dead Sea pollen record, Quaternary Sci. Rev., 49, 95–105, doi:10.1016/j.quascirev.2012.06.012, 2012.

Louis, H.: Das natürliche Pflanzenkleid Anatoliens, J. Engelhorns Nachf. Adolf Spemann, Stuttgart, 1939.

Masi, A., Sadori, L., Zanchetta, G., Baneschi, I., and Giardini, M.: Climatic interpretation of carbon isotope content of mid-Holocene archaeological charcoals from eastern Anatolia, Quatern. Int., 303, 64–72, doi:10.1016/j.quaint.2012.11.010, 2013.

Mayer, H. and Aksoy, H.: Wälder der Türkei, Gustav Fischer Verlag, Stuttgart, New York, 1986.

Mayewski, P. A., Rohling, E. E., Curt Stager, J., Karlén, W., Maasch, K. A., David Meeker, L., Meyerson, E. A., Gasse, F., van Kreveld, S., Holmgren, K., Lee-Thorp, J., Rosqvist, G., Rack, F., Staubwasser, M., Schneider, R. R., and Steig, E. J.: Holocene climate variability, Quaternary Res., 62, 243–255, doi:10.1016/j.yqres.2004.07.001, 2004.

Moore, P. D., Webb, J. A., and Collinson, M. E.: Pollen analysis, 2 Edn., Blackwell Scientific Publications, Oxford, 1991.

Mudie, P. J., Rochon, A., and Aksu, A. E.: Pollen stratigraphy of Late Quaternary cores from Marmara Sea: land-sea correlation and paleoclimatic history, Mar. Geol., 190, 233–260, doi:10.1016/S0025-3227(02)00349-3, 2002.

Müller, U. C., Pross, J., Tzedakis, P. C., Gamble, C., and Kotthoff, U.: The role of climate in the spread of modern humans into Europe, Quaternary Sci. Rev., 30, 273–279, doi:10.1016/j.quascirev.2010.11.016, 2011.

NGRIP members: High-resolution record of Northern Hemisphere climate extending into the last interglacial period, Nature, 431, 147–151, doi:10.1038/nature02805, 2004.

Öztürk, K., Yaltirak, C., and Alpar, B.: The Relationship Between the Tectonic Setting of the Lake İznik Basin and the Middle Strand of the North Anatolian Fault, Turk. J. Earth Sci., 18, 209–224, doi:10.3906/yer-0803-4, 2009.

Panagiotopoulos, K., Böhm, A., Leng, M. J., Wagner, B., and Schäbitz, F.: Climate variability over the last 92 ka in SW Balkans from analysis of sediments from Lake Prespa, Clim. Past, 10, 643–660, doi:10.5194/cp-10-643-2014, 2014.

Pichler, H. and Friedrich, W.: Radiocarbon dates of Santorini volcanics, Nature, 262, 373–374, doi:10.1038/262373a0, 1976.

Pickarski, N., Kwiecien, O., Langgut, D., and Litt, T.: Abrupt climate and vegetation variability of eastern Anatolia during the last glacial, Clim. Past, 11, 1491–1505, doi:10.5194/cp-11-1491-2015, 2015.

Prentice, I. C., Guiot, J., Huntley, B., Jolly, D., and Cheddadi, R.: Reconstructing biomes from palaeoecological data: a general method and its application to European pollen data at 0 and 6 ka, Clim. Dynam., 12, 185–194, doi:10.1007/s003820050102, 1996.

Rasmussen, S. O., Bigler, M., Blockley, S. P., Blunier, T., Buchardt, S. L., Clausen, H. B., Cvijanovic, I., Dahl-Jensen, D., Johnsen, S. J., Fischer, H., Gkinis, V., Guillevic, M., Hoek, W. Z., Lowe, J. J., Pedro, J. B., Popp, T., Seierstad, I. K., Steffensen, J. P., Svensson, A. M., Vallelonga, P., Vinther, B. M.,Walker, M. J. C., Wheatley, J. J., and Winstrup, M.: A stratigraphic framework for abrupt climatic changes during the Last Glacial period based on three synchronized Greenland ice-core records: refining and extending the INTIMATE event stratigraphy, Quaternary Sci. Rev., 106, 14–28, doi:10.1016/j.quascirev.2014.09.007, 2014.

Reille, M.: Pollen et spores d'Europe et d'Afrique du Nord: supplement 1, Laboratoire de Botanique Historique et Palynologie, Marseille, 1995.

Reille, M.: Pollen et spores d'Europe et d'Afrique du Nord: supplement 2, Laboratoire de Botanique Historique et Palynologie, Marseille, 1998.

Reille, M.: Pollen et spores d'Europe et d'Afrique du Nord, 2 Edn., Laboratoire de Botanique Historique et Palynologie, Marseille, 1999.

Richter, J., Melles, M., and Schäbitz, F.: Temporal and spatial corridors of Homo sapiens sapiens population dynamics during the Late Pleistocene and early Holocene, Quatern. Int., 274, 1–4, doi:10.1016/j.quaint.2012.06.009, 2012.

Roberts, N.: Human-induced landscape change in South and Southwest Turkey during the later Holocene, in: Man's Role in the Shaping of the Eastern Mediterranean Landscape, edited by: Bottema, S., Entjes-Nieborg, G., and van Zeist, W., Balkema, Rotterdam, 53–66, 1990.

Roberts, N. and Wright, H. E.: Vegetational, lake-level, and climatic history of near East and Southwest Asia, in: Global Climates since the Last Glacial Maximum, edited by: Wright, H. E., Kutzbach, J. E.,Webb, T., Ruddiman,W. F., Street-Perrott, F. A., and Bartlein, P., J., University of Minnesota Press, Minneapolis, London, 194–220, 1993.

Roberts, N., Eastwood, W. J., Kuzucuoğlu, C., Fiorentino, G., and Caracuta, V.: Climatic, vegetation and cultural change in the eastern Mediterranean during the mid-Holocene environmental transition, Holocene, 21, 147–162, doi:10.1177/0959683610386819, 2011.

Robinson, S. A., Black, S., Sellwood, B. W., and Valdes, P. J.: A review of palaeoclimates and palaeoenvironments in the Levant and Eastern Mediterranean from 25,000 to 5000 years BP:

setting the environmental background for the evolution of human civilisation, Quaternary Sci. Rev., 25, 1517–1541, doi:10.1016/j.quascirev.2006.02.006, 2006.

Roeser, P.: Paleolimnology of Lake Iznik (NW Turkey) during the past ~31 ka cal BP, PhD thesis, Rheinische Friedrich-Wilhelms-Universitat Bonn, Bonn, 202 pp., 2014.

Roeser, P., Franz, S. O., and Litt, T.: Aragonite and calcite preservation in lacustrine sediments related to bottom lake oxygenation and water column depth, Sedimentology, in review, 2016.

Roeser, P. A., Franz, S. O., Litt, T., Ulgen, U. B., Hilgers, A., Wulf, S., Wennrich, V., On, S. A., Viehberg, F. A., Ca.gatay, M. N., and Melles, M.: Lithostratigraphic and geochronological framework for the paleoenvironmental reconstruction of the last ~36 ka cal BP from a sediment record from Lake Iznik (NW Turkey), Quatern. Int., 274, 73–87, doi:10.1016/j.quaint.2012.06.006, 2012.

Roodenberg J. and Roodenberg, S. A. (Eds.): Life and Death in a Prehistoric Settlement in Northwest Anatolia: The Ilıpınar Excavations, Volume III, Nederlands Instituut voor het Nabije Oosten, Leiden, 2008.

Rossignol-Strick, M.: Sea-land correlation of pollen records in the eastern Mediterranean for the glacial-interglacial transition, Quaternary Sci. Rev., 14, 893–915, doi:10.1016/0277-3791(95)00070-4, 1995.

Sadori, L. and Narcisi, B.: The Postglacial record of environmental history from Lago di Pergusa, Sicily, Holocene, 11, 655–671, doi:10.1191/09596830195681, 2001.

Sadori, L., Giardini, M., Gliozzi, E., Mazzini, I., Sulpizio, R., van Welden, A., and Zanchetta, G.: Vegetation, climate and environmental history of the last 4500 years at lake Shkodra (Albania/Montenegro), Holocene, 25, 435–444, doi:10.1177/0959683614561891, 2015.

Sagona, A. and Zimansky, P.: Ancient Turkey, RoutledgeWorld Archaeology, Routledge, Abingdon, New York, 2009.

Şahin, S.: İznik (Nicaea) in the Hellenistic and Roman Periods, in: İznik Throughout History, edited by: Akbaygil, I., İnalcık, H., and Aslanapa, O., Türkiye İş Bankası Kültür Yayınları, Istanbul, 3–23, 2003.

Sanchez Goñi, M. F. and Harrison, S. P.: Millennial-scale climate variability and vegetation changes during the Last Glacial: Concepts and terminology, Quaternary Sci. Rev., 29, 2823–2827, doi:10.1016/j.quascirev.2009.11.014, 2010.

Şenkul, Ç. and Doğan, U.: Vegetation and climate of Anatolia and adjacent regions during the Last Glacial period, Quatern. Int., 302, 110–122, doi:10.1016/j.quaint.2012.04.006, 2013.

Sevink, J., van Bergen, M. J., van der Plicht, J., Feiken, H., Anastasia, C., and Huizinga, A.: Robust date for the Bronze Age Avellino eruption (Somma-Vesuvius): 3945 ± 10 calBP (1995 ± 10 calBC), Quaternary Sci. Rev., 30, 1035–1046, doi:10.1016/j.quascirev.2011.02.001, 2011.

Shumilovskikh, L. S., Tarasov, P., Arz, H. W., Fleitmann, D., Marret, F., Nowaczyk, N., Plessen, B., Schlütz, F., and Behling, H.: Vegetation and environmental dynamics in the southern Black Sea region since 18 kyr BP derived from the marine core 22-GC3, Palaeogeogr. Palaeocl., 337–338, 177–193, doi:10.1016/j.palaeo.2012.04.015, 2012.

Shumilovskikh, L. S., Fleitmann, D., Nowaczyk, N. R., Behling, H., Marret, F., Wegwerth, A., and Arz, H. W.: Orbital- and millennial-scale environmental changes between 64 and 20 ka BP recorded in Black Sea sediments, Clim. Past, 10, 939–954, doi:10.5194/cp-10-939-2014, 2014.

Staubwasser, M. and Weiss, H.: Holocene climate and cultural evolution in late prehistoric–early historic West Asia, Quaternary Res., 66, 372–387, doi:10.1016/j.yqres.2006.09.001, 2006.

Stockmarr, J.: Tablets with spores used in absolute pollen analysis, Pollen et Spores, 13, 615–621, 1971.

Sulpizio, R., Van Welden, A., Caron, B., and Zanchetta, G.: The Holocene tephrostratigraphic record of Lake Shkodra (Albania and Montenegro), J. Quaternary Sci., 25, 633–650, doi:10.1002/jqs.1334, 2010.

Tarasov, P. E., Cheddadi, R., Guiot, J., Bottema, S., Peyron, O., Belmonte, J., Ruiz-Sachez, V., Saad, F., and Brewer, S.: A method to determine warm and cool steppe biomes from pollen data; application to the Mediterranean and Kazakhstan regions, J. Quaternary Sci., 13, 335–344, 1998.

Torfstein, A., Goldstein, S. L., Stein, M., and Enzel, Y.: Impacts of abrupt climate changes in the Levant from Last Glacial Dead Sea levels, Quaternary Sci. Rev., 69, 1–7, doi:10.1016/j.quascirev.2013.02.015, 2013.

Tzedakis, P. C.: Seven ambiguities in the Mediterranean palaeoenvironmental narrative, Quaternary Sci. Rev., 26, 2042–2066, doi:10.1016/j.quascirev.2007.03.014, 2007.

Tzedakis, P. C., Frogley, M. R., Lawson, I. T., Preece, R. C., Cacho, I., and de Abreu, L.: Ecological thresholds and patterns of millennial-scale climate variability: The response of vegetation in Greece during the last glacial period, Geology, 32, 109–112, doi:10.1130/G20118.1, 2004.

Ülgen, U. B., Franz, S. O., Biltekin, D., Çagatay, M. N., Roeser, P. A., Doner, L., and Thein, J.: Climatic and environmental evolution of Lake Iznik (NW Turkey) over the last ~4700 years, Quatern. Int., 274, 88–101, doi:10.1016/j.quaint.2012.06.016, 2012.

Valsecchi, V., Sánchez-Goñi, M. F., and Londeix, L.: Vegetation dynamics in the Northeastern Mediterranean region during the past 23 000 yr: insights from a new pollen record from the Sea of Marmara, Clim. Past, 8, 1941–1956, doi:10.5194/cp-8-1941-2012, 2012.

van Zeist, W. and Bottema, S.: Late Quaternary vegetational and climatic history of southwest Asia, P. Indian Nat. Sci. Acad. A, 54, 461–480, 1988.

van Zeist, W. and Bottema, S.: Late Quaternary Vegetation of the Near East, Beihefte zum Tübinger Atlas des Vorderen Orients, Dr. Ludwig Reichert, Wiesbaden, 1991.

van Zeist, W., Woldring, H., and Stapert, D.: Late Quaternary vegetation and climate of southwestern Turkey, Palaeohistoria, 17, 55–143, 1975.

Viehberg, F. A., Ülgen, U. B., Damcı, E., Franz, S. O., Ön, S. A., Roeser, P. A., Çağatay, M. N., Litt, T., and Melles, M.: Seasonal hydrochemical changes and spatial sedimentological variations in Lake Iznik (NW Turkey), Quatern. Int., 274, 102–111, doi:10.1016/j.quaint.2012.05.038, 2012.

Walker, M., Johnsen, S., Rasmussen, S. O., Steffensen, J.-P., Popp, T., Gibbard, P., Hoek, W. Z., Lowe, J. J., Andrews, J., Björck, S., Cwynar, L. C., Hughen, K. A., Kershaw, P., Kromer, B., Litt, T., Lowe, D. J., Nakagawa, T., Newnham, R. M., and Schwander, J.: The Global Stratotype Section and Point (GSSP) for the base of the Holocene Series/Epoch (Quaternary System/Period) in the NGRIP ice core, Episodes, 31, 264–267, 2008.

Weiss, E.: "Beginnings of Fruit Growing in the Old World" – two generations later, Isr. J. Plant Sci., 62, 75–85, doi:10.1080/07929978.2015.1007718, 2015.

Weninger, B., Clare, L., Rohling, E. J., Bar-Yosef, O., Böhner, U., Budja, M., Bundschuh, M., Feurdean, A., Gebel, H.-G., and Jöris, O.: The impact of rapid climate change on prehistoric societies during the Holocene in the Eastern Mediterranean, Documenta Praehistorica, 36, 7–59, doi:10.4312/dp.36.2, 2009.

Wester, R.: Wasserwirtschaftlicher Rahmenplan für das Izniksee-Gebiet/Türkei, Diploma thesis, Fachhochschule Mainz, Mainz, 1989.

Wick, L., Lemcke, G., and Sturm, M.: Evidence of Lateglacial and Holocene climatic change and human impact in eastern Anatolia: high-resolution pollen, charcoal, isotopic and geochemical records from the laminated sediments of Lake Van, Turkey, Holocene, 13, 665–675, doi:10.1191/0959683603hl653rp, 2003.

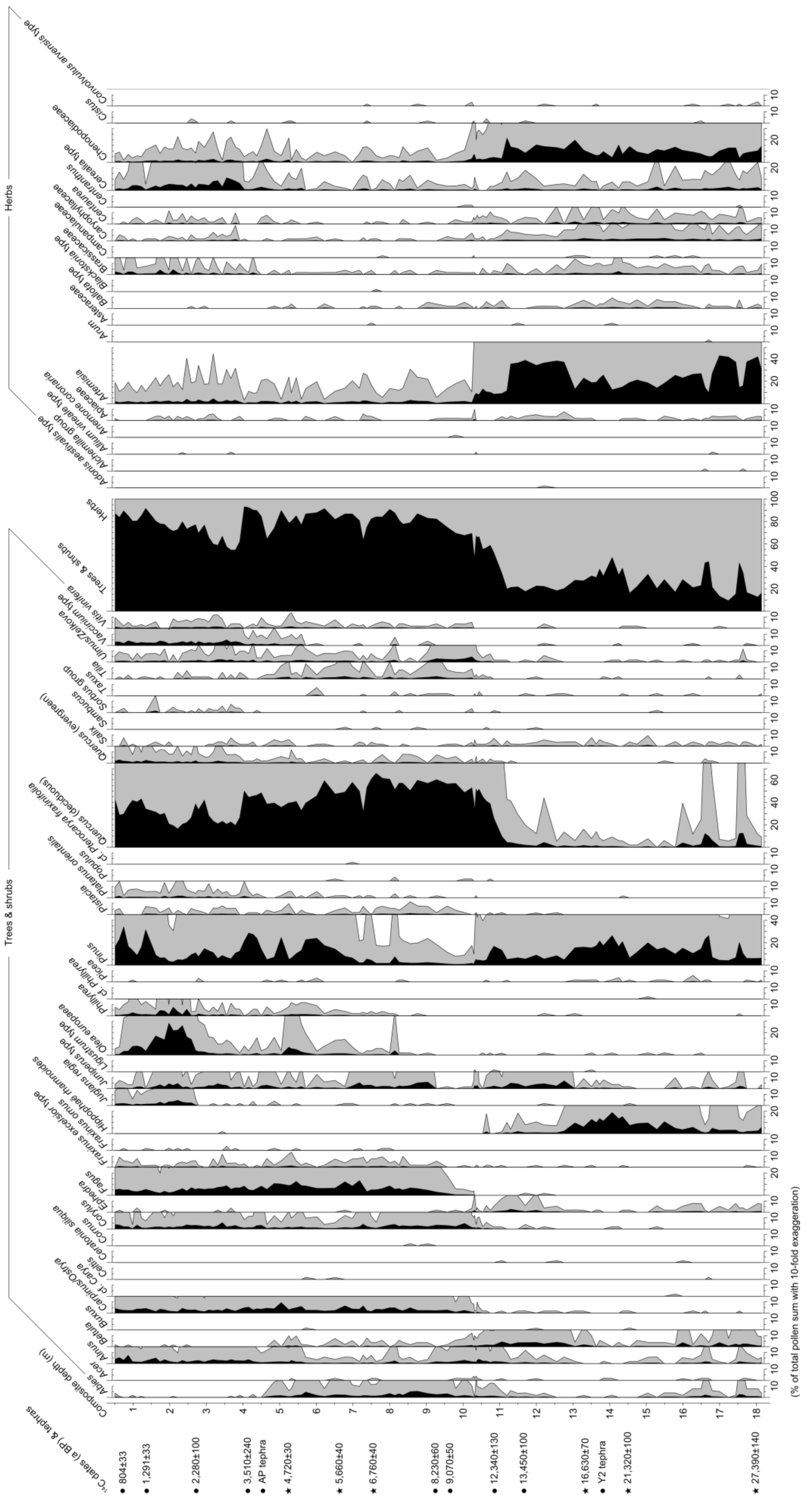
Wulf, S., Kraml, M., Brauer, A., Keller, J., and Negendank, J. F. W.: Tephrochronology of the 100 ka lacustrine sediment record of Lago Grande di Monticchio (southern Italy), Quatern. Int., 122, 7–30, doi:10.1016/j.quaint.2004.01.028, 2004.

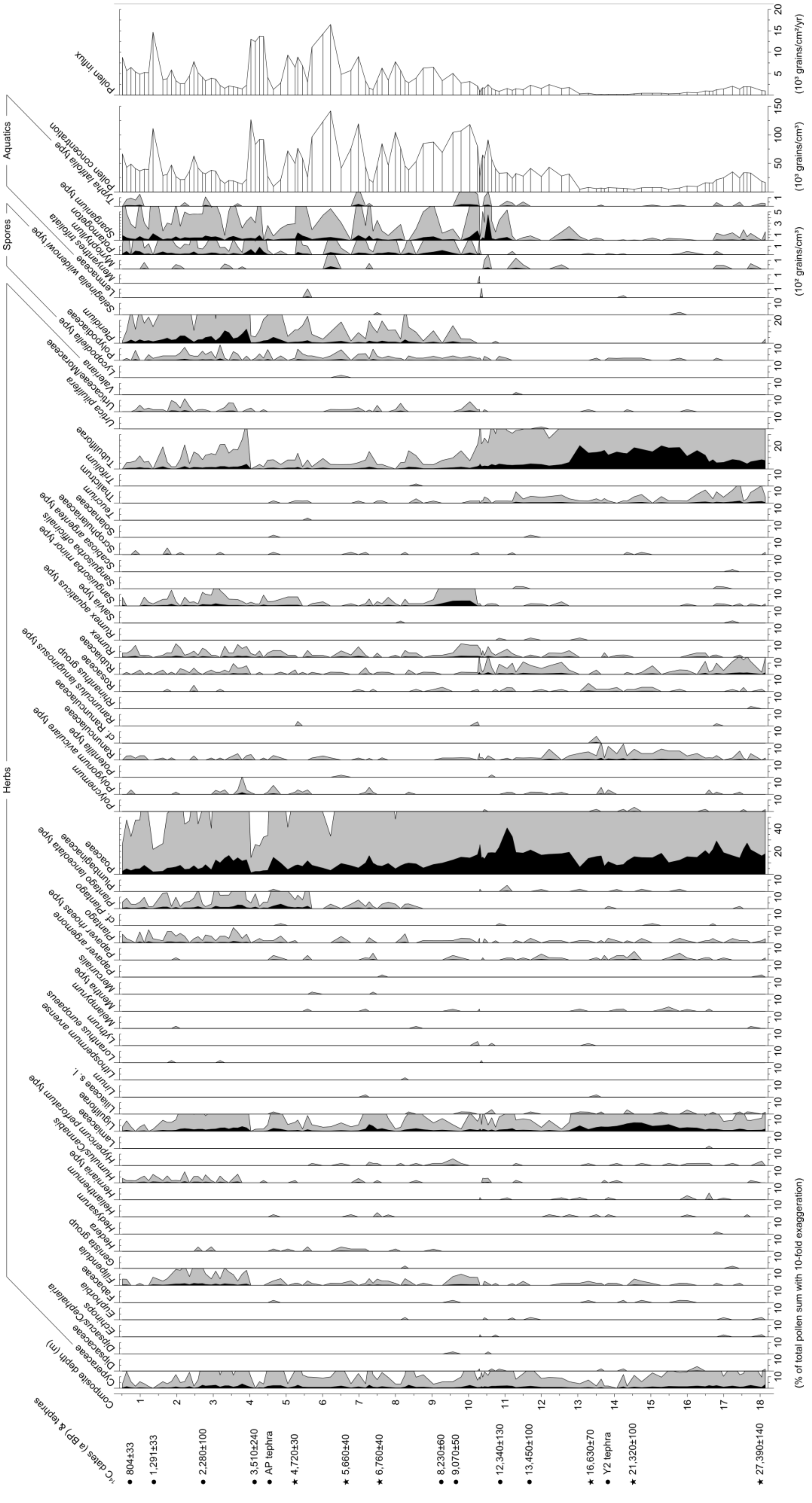
Yokoyama, Y., Lambeck, K., Deckker, P., Johnston, P., and Fifield, L. K.: Timing of the Last Glacial Maximum from observed sea-level minima, Nature, 406, 713–716, doi:10.1038/35021035, 2000.

Zohary, M.: Geobotanical Foundations of the Middle East, Gustav Fischer Verlag, Stuttgart, 1973.

2.10 Supplementary material

Complete pollen diagram inferred from Lake Iznik sediments with terrestrial plants in percentages, aquatic plants in concentrations, total pollen concentrations, and total pollen influxes (pollen accumulations). Uncalibrated radiocarbon dates and tephra layers according to Ülgen et al. (2012) and Roeser (2014). Radiocarbon dates marked by a star are from bulk organic and are therefore subjected to reservoir effects.


¹⁴C dates (a BP) & tephras
Composite depth (m)
● 804±33
● 1,291±33
● 2,280±100
● 3,510±240
● AP tephra
★ 4,720±30
★ 5,660±40
★ 6,760±40
● 8,230±60
● 9,070±50
● 12,340±130
● 13,450±100
★ 16,630±70
● Y2 tephra
★ 21,320±100
★ 27,390±140
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
Trees & shrubs
Abies
Acer
Alnus
Betula
Buxus
Carpinus/Ostrya
cf. Carya
Celtis
Ceratonia siliqua
Cornus
Corylus
Ephedra
Fagus
Fraxinus excelsior type
Fraxinus ornus
Hippophaë rhamnoides
Juglans regia
Juniperus type
Ligustrum type
Olea europaea
Phillyrea
cf. Phillyrea
Picea
Pinus
Pistacia
Platanus orientalis
Populus
cf. Pterocarya fraxinifolia
Quercus (deciduous)
Quercus (evergreen)
Salix
Sambucus
Sorbus group
Taxus
Tilia
Ulmus/Zelkova
Vaccinium type
Vitis vinifera
Trees & shrubs
Herbs
Herbs
Adonis aestivalis type
Alchemilla group
Allium vineale type
Anemone coronaria
Apiaceae
Artemisia
Arum
Asteraceae
Ballota type
Blackstonia type
Brassicaceae
Campanulaceae
Caryophyllaceae
Centaurea
Cerastium
Cerealia type
Chenopodiaceae
Cistus
Convolvulus arvensis type
10
20
40
60
80
100
(% of total pollen sum with 10-fold exaggeration)


Pollen influx
Pollen concentration
Aquatics
Typha latifolia type
Sparganium
Potamogeton
Myriophyllum
Menyanthes trifoliata
Lemnaceae
Spores
Selaginella wildenowii type
Pteridium
Polypodiaceae
Lycopodiella type
Valeriana
Urticaceae/Moraceae
Urtica pilulifera
Herbs
Tubuliflorae
Trifolium
Thalictrum
Teucrium
Solanaceae
Scrophulariaceae
Scabiosa argentea type
Sanguisorba officinalis
Sanguisorba minor type
Salvia type
Rumex aquaticus type
Rumex
Rubiaceae
Rosaceae
Rhinanthus group
Ranunculus lanuginosus type
Ranunculaceae
cf. Ranunculaceae
Potentilla type
Polygonum aviculare type
Polycnemum
Poaceae
Plumbaginaceae
Plantago lanceolata type
Plantago
cf. Plantago
Papaver rhoeas type
Papaver argemone
Mercurialis
Mentha type
Melampyrum
Lythrum
Loranthus europaeus
Lithospermum arvense
Linum
Liliaceae s. l.
Liguliflorae
Lamiaceae
Hypericum perforatum type
Humulus/Cannabis
Herniaria type
Helianthemum
Hedysarum
Hedera
Genista group
Filipendula
Fabaceae
Euphorbia
Echinops
Dipsacus/Cephalaria
Dipsacaceae
Cyperaceae
Composite depth (m)
^{14}C dates (a BP) & tephras
20 15 10 5
(10³ grains/cm²/yr)
150 100 50
(10³ grains/cm³)
(10² grains/cm³)
(% of total pollen sum with 10-fold exaggeration)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
● 804±33
● 1,291±33
● 2,280±100
● 3,510±240
● AP tephra
★ 4,720±30
★ 5,660±40
★ 6,760±40
● 8,230±60
● 9,070±50
● 12,340±130
● 13,450±100
★ 16,630±70
● Y2 tephra
★ 21,320±100
★ 27,390±140

3 Vegetation and climate during the Last Glacial high stand (ca. 28–22 ka BP) of the Sea of Galilee, northern Israel[1]

3.1 Abstract

Despite ongoing discussions on hydroclimatic conditions in the southern Levant during the Last Glacial, detailed knowledge about the Levantine paleovegetation, which is an important indicator for the paleoclimate, is limited. To investigate the paleovegetation in northern Israel, we analyzed the pollen assemblage of a sediment core that was drilled at the Ohalo II archaeological site on the southwestern shore of the Sea of Galilee (Lake Kinneret). We refined the lithology and the age-depth model with the help of five new radiocarbon dates. The core comprises a continuous sediment profile of mainly laminated authigenic calcites and detrital material that deposited between ca. 28,000 and 22,500 years before present, when the Sea of Galilee rose above the modern lake level stand and temporarily merged with Lake Lisan, the precursor of the Dead Sea. The well-dated and high-resolution pollen record suggests that steppe vegetation with grasses, other herbs, and dwarf shrubs predominated in northern Israel during the investigated period. In contrast to the Holocene, there was no continuous and dense Mediterranean woodland belt in the vicinity of the Sea of Galilee. Deciduous oaks were the dominant trees, although they only occurred in limited amounts. These results disagree with previous pollen-based hypotheses from the region that assumed the spread of Mediterranean forest during glacial periods. While the pollen data may indicate semiarid conditions in northern Israel and give no evidence of increased effective moisture, previous hydroclimatic studies suggested increased precipitation rates that are consistent with high lake levels (Sea of Galilee/Lake Lisan). Thus, we discuss factors influencing the pollen assemblage and the plant cover.

3.2 Introduction

The Levant, lying at the transition of the Saharo-Arabian desert belt and the subtropical Mediterranean region, is a key area for investigating the relationship between past vegetation dynamics, climate changes, and human history (e.g., Frumkin et al., 2011; Richter et al., 2012). The Dead Sea rift valley was a possible migration route of modern humans (Richter et al., 2012) and accommodated some early prehistorical settlements, e.g. the Ohalo II site in the vicinity of the Sea of Galilee (Lake Kinneret) dating back to the Last Glacial (Nadel, 1990; Nadel et al., 1995). During the Last Glacial, the Sea of Galilee and Lake Lisan (the precursor of the Holocene Dead Sea) rose to higher elevations compared to the Holocene lakes and reached maximum levels of ca. 170 m bmsl (meter below mean sea level) when both lakes converged (Bartov et al., 2003; Hazan et al., 2005; Torfstein et al., 2013). These remarkably high lake levels point to an increased glacial wetness in the southern Levant. Other lines of evidence,

---

[1] Chapter 3 is based on Miebach, A.; Chen, C.; Schwab, M. J.; Stein, M.; Litt, T. (2016): Vegetation and climate during the Last Glacial high stand (ca. 28–22 ka BP) of the Sea of Galilee, northern Israel. Quaternary Science Reviews: under review.

e.g. the deposition of speleothems in areas that were too dry for speleothem growth during the Holocene (Vaks et al., 2003, 2006) and the formation of massive travertine’s in the Beit Shean region requiring enhanced spring activity (Rozenbaum, 2009) also suggest wet glacial conditions. However, there is a long lasting debate if reduced evaporation rates or increased precipitation rates mainly triggered these hydrological conditions (Tzedakis, 2007; Torfstein et al., 2013). Reduced evaporation rates in the catchment of Lake Lisan caused by low temperatures and low insolation might have caused a positive freshwater balance allowing even less precipitation than present as suggested by climate model simulations (Stockhecke et al., 2016). Such a scenario was previously suggested by Bar-Matthews et al. (1997) based on isotope data of speleothems. However, subsequent investigations suggested that these data were rather influenced by the water source composition than climatic conditions (e.g., Frumkin et al., 1999; Kolodny et al., 2005). According to Torfstein et al. (2013), reduced evaporation rates could not support the deposition of aragonite-detritus laminae, which comprise significant parts of the Lisan Formation (e.g., Begin et al., 1974; Katz et al., 1977; Machlus et al., 2000). Its deposition required a persistent annual influx of freshwater providing bicarbonate to the Ca-chloride brine (Stein et al., 1997; Barkan et al., 2001). Hence, it suggests that an increased precipitation instead of a decreased evaporation triggered the high lake level (Stein et al., 1997; Torfstein et al., 2013).

Wetter glacial conditions in the southern Levant would contrast northeastern Mediterranean climate records, which generally suggest colder and drier Last Glacial climatic conditions than today (e.g., Fleitmann et al., 2009; Pickarski et al., 2015; Miebach et al., 2016; Sadori et al., 2016), and climate model simulations, which suggest reduced glacial precipitation rates for the whole Eastern Mediterranean region (Robinson et al., 2006).

Several previous palynological studies in the southern Levant correlated pluvial climates corresponding to glacials with large amounts of arboreal pollen and the widespread occurrence of Mediterranean forests. Interpluvials corresponding to interglacials were correlated with desert and steppe vegetation (Horowitz, 1979, 1992 and references therein). However, chronologies were poor or not independent (e.g., Birkat Ram: Weinstein, 1976; southern Dead Sea: Horowitz, 1992) or they were revised afterwards (e.g., Ghab Valley: Rossignol-Strick, 1995; Hula Valley: van Zeist and Bottema, 2009).

More recent pollen analyses indicate opposite trends. Marine records from the Levantine Basin indicate a cold and dry climate during the Last Glacial (Cheddadi and Rossignol-Strick, 1995; Langgut et al., 2011) with coldest and driest conditions between 27.1 and 16.2 ka BP (kilo years before present; Langgut et al., 2011). However, despite the proximity to the Levantine coast, these marine records were influenced by a very large pollen catchment area due to the basin size and by pollen brought by the Nile. Terrestrial pollen records from Yammouneh (Lebanon) and the Birkat Ram maar lake (Golan Heights, Israel) also suggest that steppic vegetation and cold and arid climatic conditions prevailed during the Last Glacial (Gasse et al., 2011, 2015; Schiebel, 2013). However, because of the location at 1360 and 940 m amsl (meter above mean sea level), respectively, orographic climate effects were possible at both sites. A possible effect could have been water deficiency due to water storage as ice or frozen soils as proposed by Develle et al. (2011) for the Yammouneh Basin. In contrast, average temperatures of the Sea of Galilee, located at 209 m bmsl, and its proximate surrounding were still relatively high during cold periods. Interpretation of isotopes on *Melanopsis* shells as a temperature proxy by Zaarur et al. (2016) indicate that compared to today the average water temperature of the Sea of Galilee was only ca.

3 °C cooler during the LGM (Last Glacial Maximum) when global ice volume maximized at 23–19 ka BP (Mix et al., 2001).

The limnological history of the Sea of Galilee was investigated by Hazan et al. (2005). They reconstructed a lake level curve based on exposed sedimentary sections, trenches, and cores. Previous research on the paleovegetation inferred from the Sea of Galilee was carried out by Baruch (1986), Schiebel (2013), and Langgut et al. (2013, 2015), who investigated the past ca. 9,000 years. Palynological studies at the Sea of Galilee presented by Horowitz (1971, 1979) might cover the last 18,000 years. However, the sample resolution is very low and a robust chronology is lacking. A well-dated and high-resolution palynological study for the Last Glacial, particularly during the Sea of Galilee/Lake Lisan high stand, was missing.

Here, we show the results of a high-resolution palynological study from Last Glacial Sea of Galilee. In addition, we present a refined lithology and new radiocarbon dates from core KIN2 to enhance the previously published age-depth models by Hazan et al. (2005) and Lev (2014). We discuss our results with emphasis on paleoenvironmental changes including vegetation, climate, and lake level changes.

3.3 Regional setting

The Sea of Galilee is the largest freshwater lake in Israel (21 x 12 km, 168.7 km²) and with 209 m bmsl the lowest freshwater lake on the Earth (Fig. 3.1). Its maximal water depth reaches 41.7 m, and its watershed encompasses 2,730 km² (Berman et al., 2014). The main freshwater source is the Jordan River coming from the Hula Valley in the north and draining the Sea of Galilee southwards to the Dead Sea. In addition, the lake is fed by saline springs, which dictate its salinity and geochemical composition (Stiller et al., 2009; Stein, 2014).

The regional morphology is shaped by Cretaceous to Eocene carbonate rocks with extensive karst and Neogene and Pleistocene basalts (Sneh et al., 1998). Soils such as terra rossa and rendzina comprise the surface cover of the Galilee mountains (Dan et al., 1972). The Jordan Valley to the north and south of the Sea of Galilee is filled with alluvial and lacustrine sediments of Neogene to Pleistocene ages. The Sea of Galilee is located in the Kinnarot tectonic basin, which is partly filled by evaporitic and lacustrine sediments of Neogene to Pleistocene time (Stein, 2014). The basin was partly shaped by the tectonic movements associated with the Dead Sea transform (Ben-Avraham et al., 2014).

Northern Israel is currently characterized by Mediterranean climate with warm, dry summers and mild, wet winters. The annual mean precipitation and temperature vary considerably in northern Israel because of the steep topography. The Kinnarot Basin, where the Sea of Galilee is located, is locally characterized by a hot and semiarid climate with 400 mm mean annual precipitation and 21 °C mean annual temperature. The surrounding mountains are several hundred to more than thousand meter higher than the present lake level resulting in higher mean annual precipitation rates and lower mean temperatures (Mount Kennan, Upper Galilee: 718 mm, 16.1 °C; Masada, northern Golan Heights: 1042 mm, 14.4 °C (Israel Meteorological Service)). 90 % of the precipitation in northern Israel originates from the Mediterranean Sea and is brought by west winds caused by Mediterranean (Cyprus) cyclones (Dayan, 1986; Ziv et al., 2014).

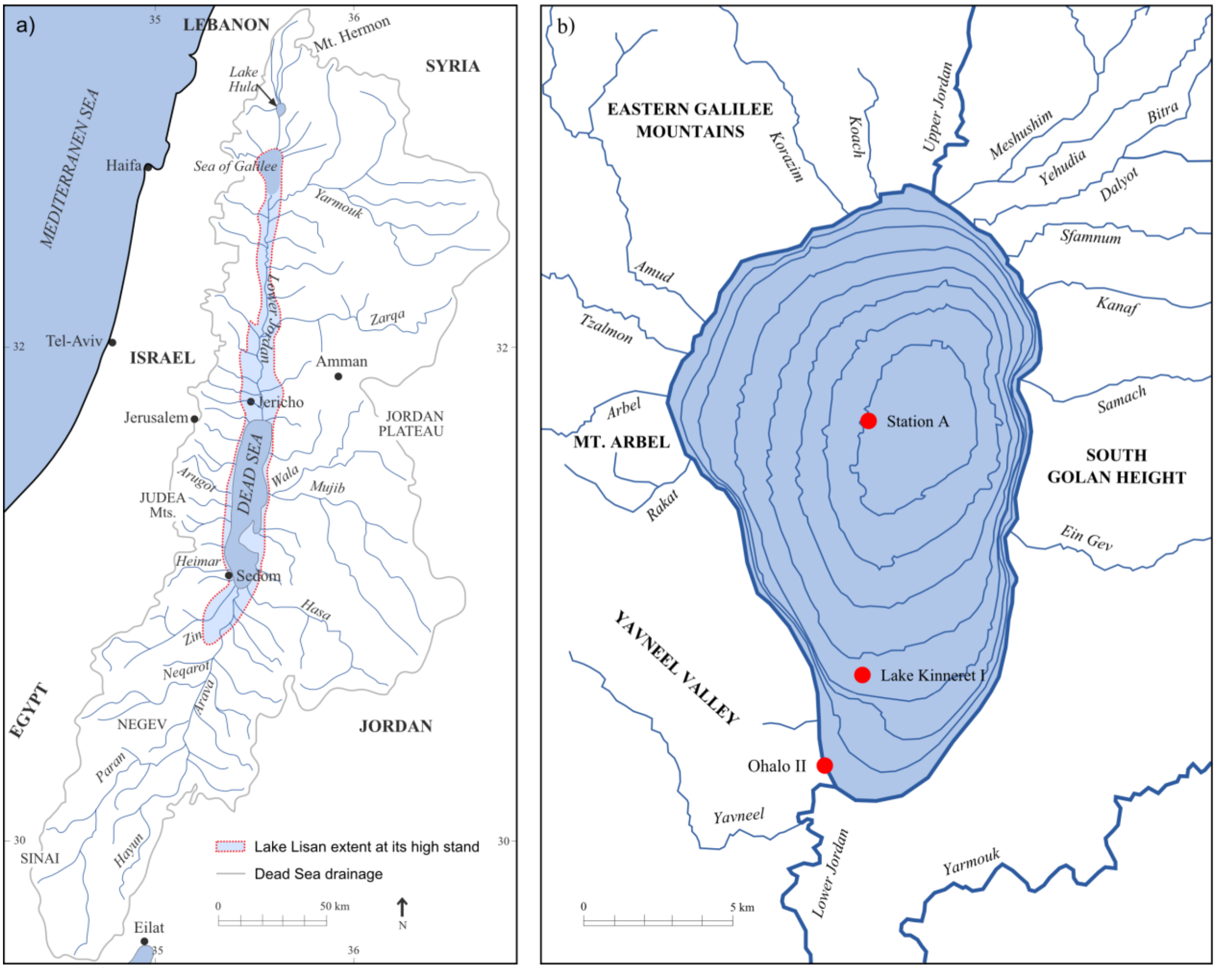


Figure 3.1: Regional setting: a) Dead Sea drainage with the extent of Lake Lisan at its highest stand (modified after Greenbaum et al., 2006), b) Sea of Galilee with coring locations (red dots) at the archaeological site Ohalo II (this study), Station A (Langgut et al., 2013, 2015; Schiebel, 2013), and Lake Kinneret I (Baruch, 1986), and with bathymetric curves at 5 m intervals (modified after Berman et al., 2014).

The vegetation in the southern Levant is strongly influenced by precipitation but also by temperature and soils. With decreasing precipitation values towards the south and east, Mediterranean woodland is displaced by Irano-Turanian steppe and Saharo-Arabian desert vegetation. The Sea of Galilee is situated in the Mediterranean vegetation belt. The region is generally characterized by arboreal climax communities (Zohary, 1962). Common trees are *Quercus* spp., *Pistacia* spp., *Ziziphus* spp., *Rhamnus* spp., *Ceratonia siliqua*, *Phillyrea latifolia*, *Styrax officinalis*, several Rosaceae species, and at higher altitudes also conifers such as *Cedrus libani* and *Juniperus excelsa* (Baruch, 1986). The Jordan Valley south of the Sea of Galilee is characterized by Irano-Turanian steppe. This vegetation type consists mainly of herbs and dwarf-shrubs and is dominated by *Artemisia herba-alba*. Nowadays, the vegetation in northern Israel is heavily altered due to human influences of several thousand years (Zohary, 1962).

3.4 Material and methods

3.4.1 Coring campaign

The coring campaign took place in December 1999 at the archaeological site of Ohalo II during a lake level low stand. The Ohalo II site is located at the southwestern shore of the Sea of Galilee at an elevation of 212–213 m bmsl and is submerged nowadays. The core KIN2 with a length of ca. 9 m was drilled at an elevation of 213 m bmsl (Fig. 3.1). At the depth of 222 m bmsl, a pebble layer was reached, which might indicate a former shoreline or riverbed (Hazan et al., 2005). Most of the core comprises laminated primary calcites and fine detritus material. For this study, we used samples and dates from core KIN2 and disregarded the composite section of different cores and trenches from the Ohalo II location as presented in Hazan et al. (2005).

3.4.2 Radiocarbon dating and age-depth model

Five new samples of charcoal, terrestrial wood, and unidentified freshwater snails were selected and prepared for accelerator mass spectroscopy (AMS) radiocarbon (^{14}C) analysis (Table 3.1). The material was cleaned with distilled water and dried. ^{14}C measurements were performed at Beta Analytic Inc, Miami, USA.

Age-depth modeling was performed based on all available radiocarbon dates from core KIN2 (Table 3.1) by *clam*, version 2.2 (Blaauw, 2010). The 13 radiocarbon dates were calibrated to calendar ages (ka cal BP; calibrated kilo years before 1950) using the INTCAL13 calibration curve (Reimer et al., 2013). A smooth spline model with a smoothing level of 0.6 was applied to the major part of the age-depth model. Only the lowermost radiocarbon date was excluded and plotted separately.

3.4.3 Palynological analyses

Pollen were extracted and prepared from sediment samples with a specific volume of 3.5–11 cm^3 following a standard protocol described by Faegri and Iversen (1989). The chemical treatment included 10 % hot hydrochloric acid (HCl; 10 minutes), 10 % hot potassium hydroxide (KOH; 25 minutes), 40 % hydrofluoric acid (HF; at least 48 hours), 10 % hot HCl (10 minutes), glacial acetic acid ($C_2H_4O_2$), hot acetolysis with 1 part concentrated sulfuric acid (H_2SO_4) and 9 parts concentrated acetic anhydrite ($C_4H_6O_3$; max. 3 minutes), and $C_2H_4O_2$. Sieving of coarser particles than 200 µm and ultrasonic sieving of finer particles than 10 µm were conducted. Pollen and NPP (non-pollen palynomorph) concentrations were calculated with the help of *Lycopodium* tablets with 18,584 ± 371 spores that were added to each sample prior to the chemical treatment (Stockmarr, 1971). Samples were preserved in glycerol and were stained with safranin.

Table 3.1: Radiocarbon dates from core KIN2. Calibrated ages are given as the mean of the 95 % confidence interval.

Sample ID	Material	Core segment	Segment depth (cm)	Mean composite depth (cm)	Radiocarbon age (a BP)	Estimated reservoir age (a)	Calibrated age (a cal BP)	Reference
AMS 01	wood & charcoal	KIN2-1	4–9	28.5	18,630 ± 60	-	22,504	this paper
KIN2 2251	charcoal	KIN2-1	60–63	83.5	19,400 ± 100	-	23,343	Lev, 2014
AMS 02-1	charcoal	KIN2-2	54–56	173.5	19,630 ± 60	-	23,655	this paper
AMS 02-2	charcoal	KIN2-2	56–60	176.5	19,740 ± 90	-	23,771	this paper
KIN2 2257	charcoal	KIN2-2	60–63	180	19,600 ± 100	-	23,623	Lev, 2014
KIN2 2257	ostracods	KIN2-2	60–63	180	19,600 ± 200	0	23,577	Lev, 2014
KIN2 2258	ostracods	KIN2-2	80–83	200	19,900 ± 400	0	24,033	Lev, 2014
Kin 2-3A-2	*Melanopsis*	KIN2-3A	18.5–19	236.25	21,420 ± 160	1500	23,966	Hazan et al., 2005
KIN2 2264	charcoal	KIN2-3A	80–83	299	20,000 ± 100	-	24,065	Lev, 2014
KIN2 2267	charcoal	KIN2-3B	20–23	330	20,800 ± 100	-	25,029	Lev, 2014
AMS 09-2	wood	KIN2-5B	25–26.5	687.25	22,900 ± 90	-	27,254	this paper
AMS 13-2	unidentified freshwater snails	KIN2-6A	85.5–88	846.25	25,390 ± 110	1500	27,954	this paper
Kin 2-6B	*Melanopsis*	KIN2-6B	35–38	891	40,510 ± 1280	1500	43,391	Hazan et al., 2005

Palynomorphs were identified with Zeiss Axio Lab.A1 light microscopes with the help of palynomorph keys (Reille, 1995, 1998, 1999; Chester and Raine, 2001; Beug, 2004) and the pollen reference collection of the Steinmann Institute, University of Bonn. At least 500 terrestrial pollen grains were counted in each sample (joint analyses by Chunzhu Chen and Andrea Miebach). Obligate aquatic plants were excluded from the total pollen sum to exclude local taxa growing in the lake (Moore et al., 1991). Furthermore, destroyed and unknown pollen were excluded from the total pollen sum, which was used to calculate percentages of the pollen assemblage. *Alnus*, *Fraxinus*, *Platanus orientalis*, *Salix*, *Tamarix*, *Ulmus*, and *Vitis* were grouped as riverine trees and shrubs following van Zeist et al. (2009).

Pollen diagrams were prepared with Tilia, Version 1.7.16 (© 1991–2011 Eric C. Grimm). A stratigraphically constrained cluster analysis using a square root transformation was applied by CONISS (Grimm, 1987).

The complete palynological dataset including several rare taxa, which are not shown in the pollen diagram, is available on the PANGAEA database (www.pangaea.de).

3.5 Results and discussion

3.5.1 Chronology

Previously obtained radiocarbon dates by Hazan et al. (2005) and Lev (2014) as well as new radiocarbon dates are presented in Table 3.1. The age-depth model is shown in Fig. 3.2.

Radiocarbon dating of lacustrine carbonates (here shells of ostracods, *Melanopsis*, and unidentified freshwater snails) is potentially biased by a reservoir effect and/or a hard water effect. Parallel dating of charcoal and ostracods from the same sediment horizon yielded the same uncalibrated ^{14}C date, although the error of the ostracods sample was larger (Lev, 2014). This implies that these ostracods do not have a relevant reservoir age. Therefore, no reservoir correction was applied to both ostracods samples. The reservoir and hard water effect on *Melanopsis*, a common freshwater snail in Israel, strongly depends on their habitat water. Lev et al. (2007) determined reservoir ages for *Melanopsis* in several water habitats in northern Israel between ca. 750 and 7200 years. For the Sea of Galilee, they measured a reservoir age of ca. 750 years on living *Melanopsis*. Measurements on fossil *Melanopsis* yielded about the same reservoir age. Hazan et al. (2005) assumed a reservoir correction of ca. 1000 years for fossil *Melanopsis* from the Sea of Galilee. However, the inclusion of all available radiocarbon dates of KIN2 suggests a dating deviation of ca. 1500 years for *Melanopsis* (sample ID Kin 2-3A-2). Therefore, we applied a reservoir correction of 1500 years to all samples of *Melanopsis* and unidentified freshwater snails.

The modified chronology reveals a continuous sediment profile from ca. 27.9 to 22.5 ka cal BP (22–846 cm composite depth), which corresponds to marine isotope stage (MIS) 2. The uppermost date of ca. 22.5 ka cal BP determines the end of the lake level high stand and the drying of the coring location, which enabled the Epipaleolithic fisher-hunter-gatherers to live at the archaeological site Ohalo II. The date fits radiocarbon dates from the archaeological settlement, which range between ca. 21.2 and 25.2 ka cal BP (17,500–21,050 BP; Nadel et al., 1995). According to the new chronology of core KIN2, the lake level rise that eventually resulted in the mergence of Lake Lisan and the Sea of Galilee started no later than ca. 27.9 ka cal BP. This slightly predates previous estimations by Hazan et al. (2005; Fig. 3.4).

The lowermost dated *Melanopsis* (sample ID Kin 2-6B) might have been redeposited and might therefore led to an overestimation of the sediment age. However, a hiatus located at the lowermost part of core KIN2 between the dated horizons of 846 and 891 cm composite depth is also likely. The lowermost sediments in the core might have deposited during one or several former lake level high stands that were recorded by the southern Lake Lisan (cf. Torfstein et al., 2013; Fig. 3.4).

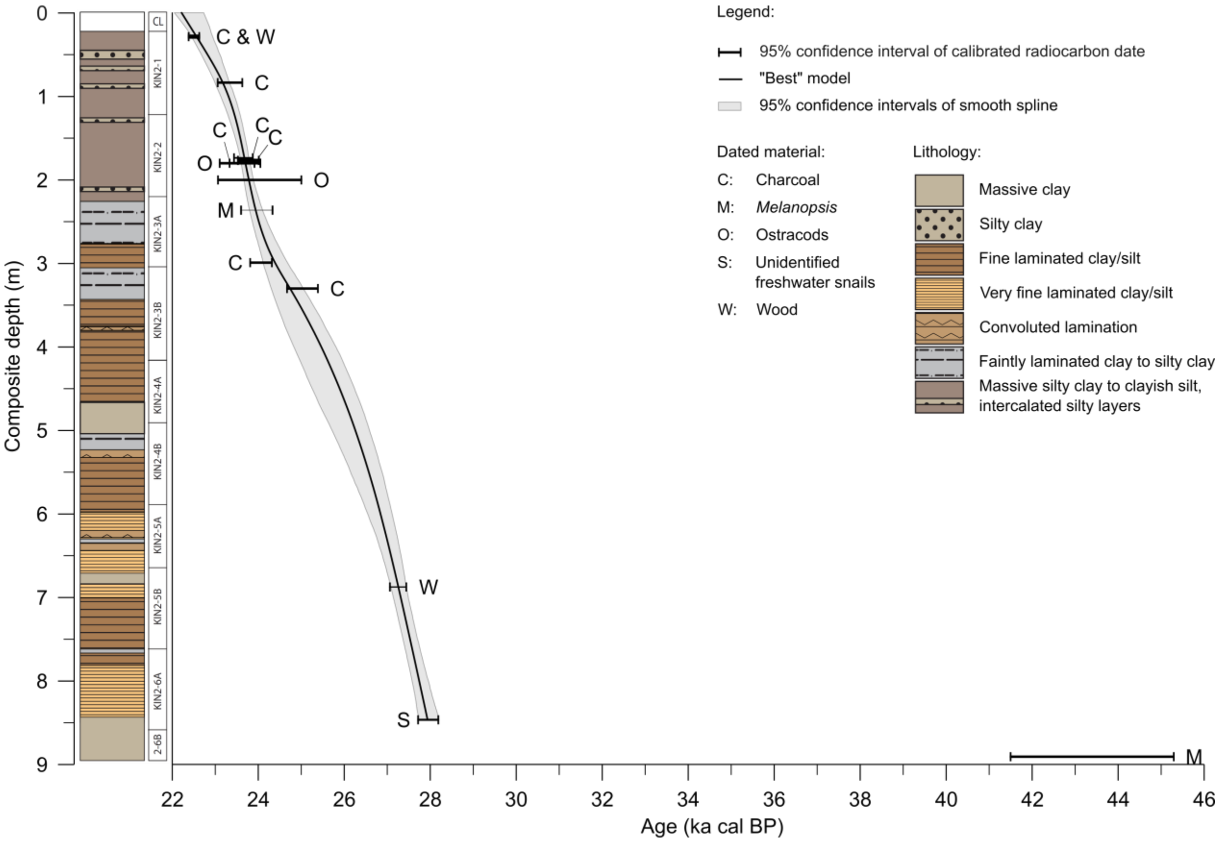


Figure 3.2: Age-depth model for core KIN2 from the Sea of Galilee with lithological profile and core segments (CL: core loss).

3.5.2 Vegetation and climate

The palynological results are summarized in Table 3.2 and Fig. 3.3. In accordance with the cluster analysis, three pollen assemblage zones (PAZs) were defined.

The occurrence of *Melanopsis* together with a pebble layer indicate a shoreline facies (Hazan et al., 2005) at the base of PAZ 3 dating back to ca. 45–41 ka cal BP. Sediments of PAZ 3 probably represent relicts of one or several former lake level high stands (cf. Torfstein et al., 2013; Fig. 3.4) but might have been partly eroded. This is supported by the rather weak pollen preservation in PAZ 3 especially in the pollen spectrum with peaking *Centaurea jacea* type percentages. High amounts of this pollen type may result from taphonomic processes and poor preservation conditions. The depositional hiatus (see 3.5.1) is probably located at the transition between PAZ 3 and 2 (Fig. 3.3). This is maintained by abrupt changes of (a) the pollen spectrum supported by the cluster analysis, (b) the pollen concentration, and (c) the lithology. Thus, a statement on the exact chronology of PAZ 3 as well as the vegetation and climate of the respective period is limited.

Table 3.2: Pollen assemblage zones (PAZs) with composite depth, age, sampling resolution, main components of pollen assemblage (AP: arboreal pollen, NAP: non-arboreal pollen, AQ: aquatics), pollen concentration (PC), and definition of lower boundary (LB).

PAZ	Composite depth (cm)	Age (ka cal BP)	No. of pollen samples/temporal resolution (years)	Pollen assemblage
1: Chenopodiaceae-Liguliflorae	25–189.5	22.5–23.7	9/148	AP: very low (1.3–11.9 %) NAP: peaks of Chenopodiaceae, Liguliflorae, and Cyperaceae AQ: strong increase of *Myriophyllum spicatum* type PC: low to high LB: increase of Chenopodiaceae
2: *Quercus-Artemisia*	189.5–843.5	23.7–27.9	45/94	AP: low (6.6–30.6 %), mainly *Quercus ithaburensis* type NAP: generally stable; predominantly Poaceae, *Artemisia,* and Chenopodiaceae AQ: low PC: moderate to high LB: increase of *Quercus ithaburensis* type, *Artemisia*, and Poaceae
3: Cyperaceae-*Centaurea*	843.5–889.5	27.9–42.7 (probably including hiatus)	6/uncertain	AP: very low (1.7–10.6 %) NAP: peaks of Chenopodiaceae, Liguliflorae, Cyperaceae, and *Centaurea jacea* type AQ: low PC: low LB: not defined (end of record)

PAZ 2 (27.9–23.7 ka cal BP) represents the vegetation during the lake level high stand and mergence of Lake Lisan with the Sea of Galilee. Irano-Turanian and Saharo-Arabian vegetation with grasses, other herbs, and dwarf-shrubs dominated the landscape. Most abundant taxa were Chenopodiaceae, Poaceae, Cerealia type, *Artemisia*, Tubuliflorae, Liguliflorae, and *Centaurea jacea* type. Also trees and shrubs occurred, which were mainly represented by deciduous oaks (*Quercus ithaburensis* type). Frost-sensitive and summer-drought-adapted trees like *Olea europaea* (olive tree), *Pistacia* (pistachio), and *Quercus calliprinos* type (evergreen oaks) were very rare. Summer insolation was minimal (Berger and Loutre, 1991; Fig. 3.4) resulting in reduced summer droughts. Still, small amounts of *Quercus calliprinos* type are commonly present in the pollen assemblage suggesting the survival of frost-sensitive plants in some refugial habitats in the vicinity of the Sea of Galilee. Pollen grains of obligate aquatic plants are almost lacking. Still, moderate amounts of Cyperaceae indicate that hydrophilic environments were close by. The majority of these pollen grains most likely originated from the littoral zone of the Sea of Galilee and point to a local component of the pollen assemblage. Some proportions of Poaceae pollen might have also originated from the littoral zone, probably from *Phragmites australis*, which is common in the surroundings of the Sea of Galilee nowadays (Zohary and Gasith, 2014). However, the deposition of laminated sediments, which prevail in PAZ 2, require a several meter thick water column above the lake floor. Moreover, an exposed shoreline dating back to ca. 26–24 ka cal BP tells that the lake level was ca. 40 m above the current shore (Hazan et al., 2005). Therefore, it proves that the coring location was not located at the MIS 2 shore, which indicates that the contribution of local plants to the pollen assemblage was low.

The comparison with the Holocene pollen assemblage from the central and southern part of the Sea of Galilee (see coring locations in Fig. 3.1) reveals major differences especially during the middle and late Holocene when trees and shrubs were much more abundant, and frost-sensitive taxa like *Olea europaea*, *Pistacia*, and evergreen oaks were more common (Baruch, 1986; Schiebel, 2013; Langgut et al., 2015). Still, arboreal pollen values of PAZ 2 and the period between ca. 9–7 ka cal BP are comparable (Schiebel, 2013; Fig. 3.4). Pollen records from the maar lake Birkat Ram show that other parts of northern Israel were already occupied by denser forests since the early Holocene (Neumann et al., 2007; Schiebel, 2013). Palynological investigations from Hula Valley point into the same direction based on the revised chronology (van Zeist et al., 2009). Still, chronological uncertainties of the Hula record are possible.

A similar difference between MIS 2 and the Holocene is visible in other Levantine pollen studies. MIS 2 was characterized by open steppe vegetation at Yammouneh, Lebanon. But an enormous change in the vegetation occurred at the beginning of MIS 1 when forests started to dominate (Gasse et al., 2011, 2015; Fig. 3.4). In marine core 9509 from the southeastern Levantine Basin, arid herbaceous flora dominated during MIS 2. An increase of arboreal pollen indicate more humid and warmer conditions during termination I and the middle to late Holocene (Langgut et al., 2011; Fig. 3.4).

The pollen assemblage of PAZ 2 from the Sea of Galilee represents steppe vegetation with some stands of oak woodland. Trees and shrubs were probably patchily distributed at advantaged habitats. The pollen assemblage suggests cooler and dryer conditions than during the middle and late Holocene (including today). The vegetation composition in the vicinity of the Sea of Galilee gives no indication for increased precipitation rates as suggested by previous investigations (e.g., Enzel et al., 2008; Torfstein et al., 2013). However, the occurrence of *Quercus ithaburensis* is not probable below a mean annual precipitation of 400 mm (Neumann et al., 2007). Moderate amounts in the pollen assemblage of PAZ 2 suggest that precipitation rates in the surrounding mountains of the Sea of Galilee, especially the Galilee Mountains as a major pollen source with 500–900 mm mean annual precipitation nowadays (Ziv et al., 2014), were not below 400–500 mm during the Last Glacial.

The apparent discrepancy between different proxies in the southern Levant, particularly between pollen records and lake level reconstructions along the Dead Sea Transform, was discussed by Tzedakis (2007). He emphasized the need for improved chronologies and high-resolution records in order not to exaggerate controversies that appear after correlating different analyses. Improved chronologies showed

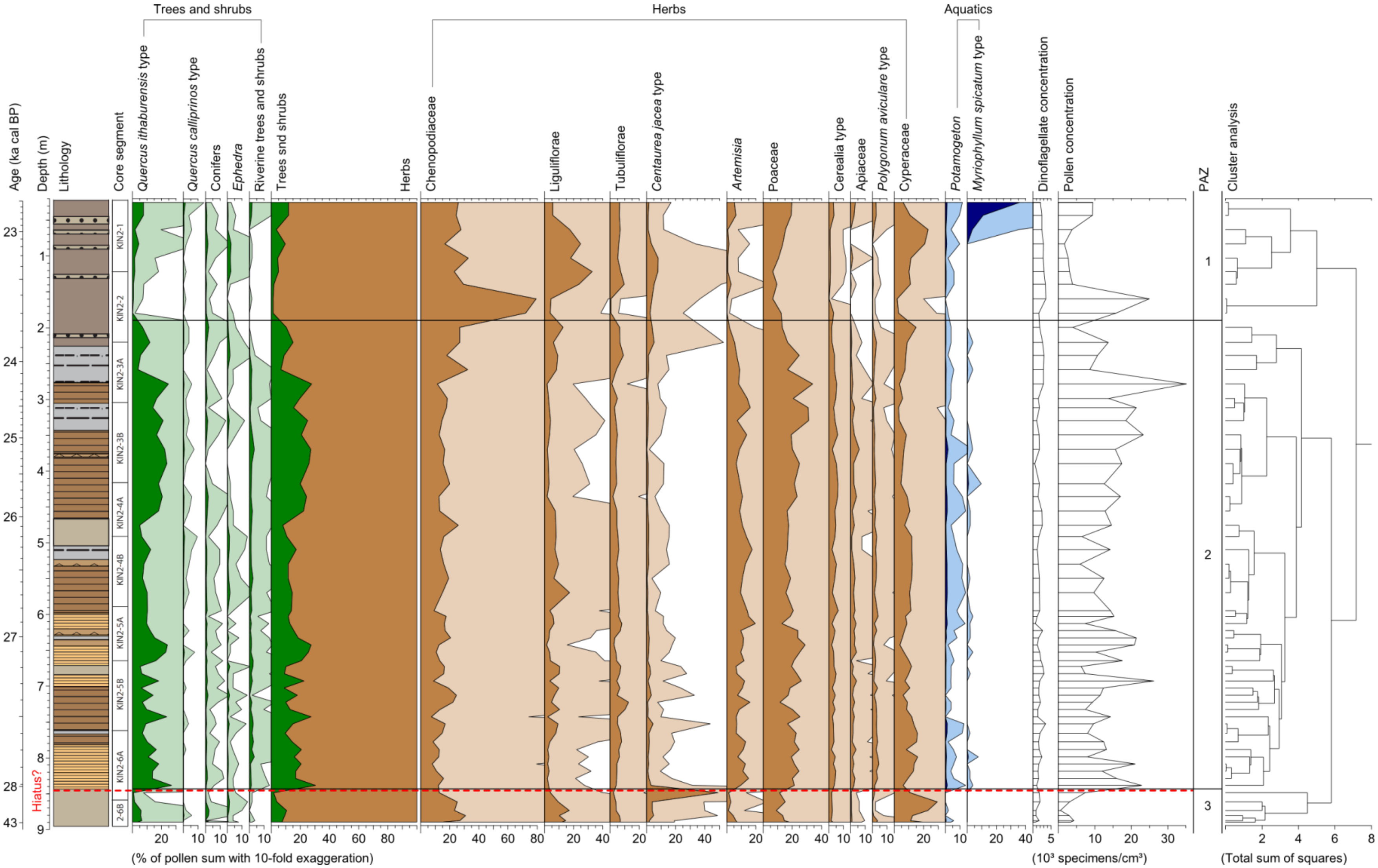


Figure 3.3: Pollen diagram from the Sea of Galilee, core KIN2, with selected taxa, pollen assemblage zones (PAZs), CONISS cluster analysis, and lithological profile (see Fig. 3.2 for the legend).

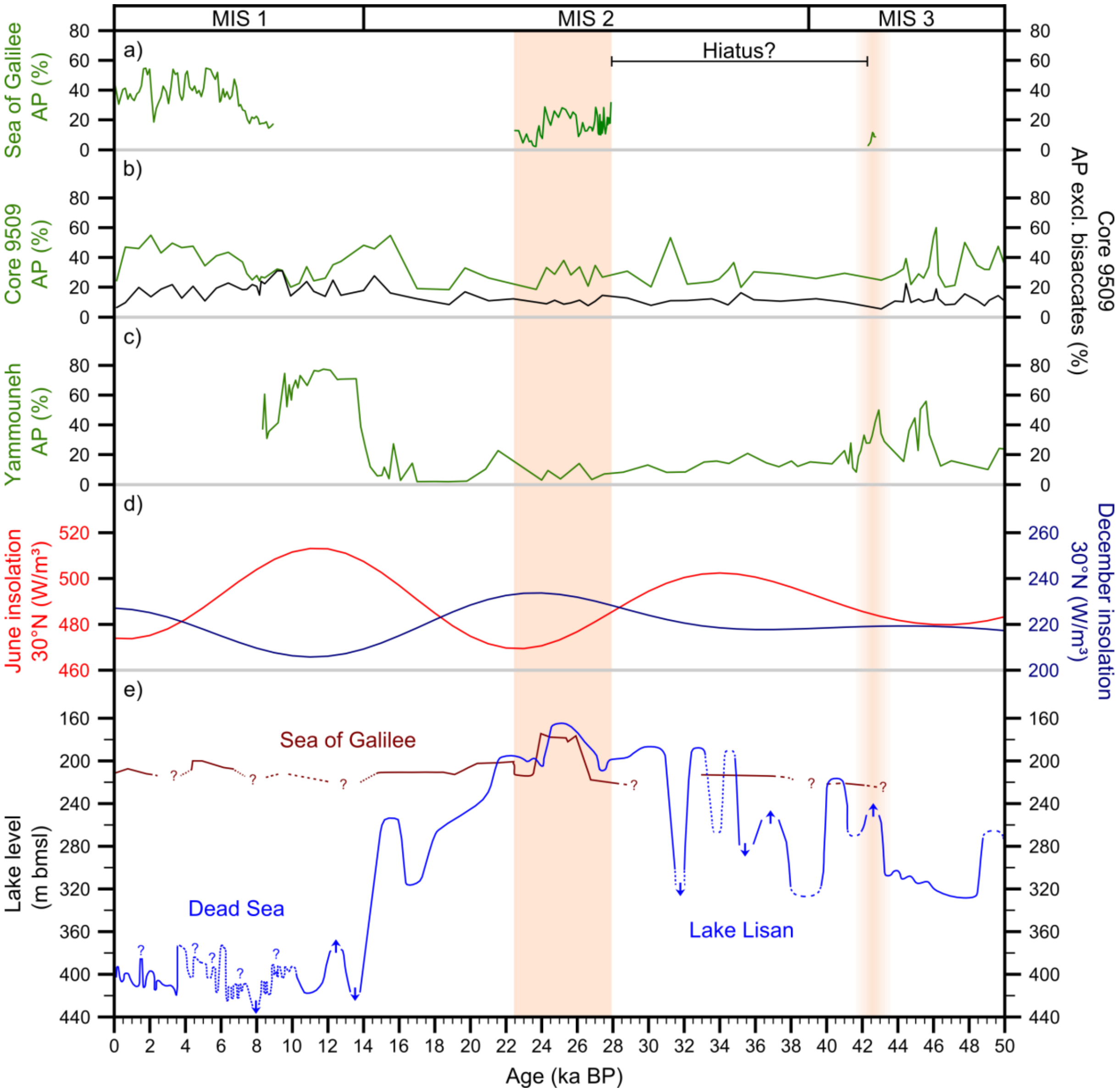


Figure 3.4: Comparison of a) AP (arboreal pollen) percentages from the Sea of Galilee: MIS 1 data (Schiebel, 2013), MIS 2 and 3 data (this study), b) percentages of AP and AP excluding bisaccate pollen from core 9509, southeastern Levantine Basin (bisaccate pollen are greatly overrepresented in marine sediments; Langgut et al., 2011), c) AP percentages from Yammouneh, Lebanon (Gasse et al., 2011, 2015), d) June and December insolation (Berger and Loutre, 1991), and e) lake level reconstructions of the Sea of Galilee (Hazan et al., 2005), the Dead Sea, and its precursor Lake Lisan (Torfstein et al., 2013). Marine isotope stages (MIS) refer to Lisiecki and Raymo (2005). Vertical bars mark the corresponding period of core KIN2 (this study).

that lake levels of Lake Lisan did not reach maximums during the LGM (23–19 ka BP) but already dropped. Therefore, at least for the LGM, there is no controversy between Lake Lisan levels and many European and northeastern Mediterranean climate records indicating coldest and driest climatic conditions (Tzedakis, 2007). We present the first well-dated and high-resolution pollen record directly from a lake occupying the Dead Sea Transform during a major lake level high stand. Still, our study resembles other palynological investigations and supports rather uniform vegetation pattern in the Eastern Mediterranean.

However, a bias of the palynological results from the Sea of Galilee should be discussed. The pollen spectrum could potentially be influenced by long distance transport from desert regions where huge amounts of dust originated that were brought to Israel (e.g., Frumkin and Stein, 2004; Haliva-Cohen et al., 2012). This could cause a shift in the pollen assemblage from Mediterranean woodland components, which would dominate under wet conditions, towards desert vegetation components. However, the pollen amount of typical Sudanian vegetation elements is negligible in the pollen record from core KIN2. Moreover, modern pollen analyses of desert dust storms show that although some pollen grains from remote desert areas might reach central/northern Israel, pollen amounts from near Mediterranean woodland always distinctively prevail (Horowitz, 1992). A Mediterranean woodland under wetter climatic conditions compared to today and without human impact would produce even more pollen.

Alternatively, the plant cover could have been shaped by effective moisture in the habitats, while additional precipitation was stored as snow on high mountains (Robinson et al., 2006). A rapid snowmelt in spring would have fed the lakes but would have hardly affected the plant cover. A similar scenario would be possible, in which the majority of precipitation released as flash floods. Especially in karstic systems such as the Galilee (Horowitz, 1979), a quick drainage of rainfall is possible. Therefore, there might have been a difference between the effective moisture available to plants and the total precipitation in the Sea of Galilee watershed.

The upper part of PAZ 2 (24.1–23.7 ka cal BP) represents the start of a lake level retreat of the Sea of Galilee. Arid herbaceous plants spread and the pollen concentration as an indicator for the density of plant cover decreases. These changes appear at the start of Heinrich Event 2 just before the LGM, and mark the end of an interval with prolonged interstadial conditions (Tzedakis, 2007 and references therein). The shifts in the pollen assemblage are in good agreement with lithological changes (Fig. 3.3) and the lake level reconstruction of the Sea of Galilee (Hazan et al., 2005; Fig. 3.4).

PAZ 1 (23.7–22.5 ka cal BP) corresponds to the lake level decrease that eventually resulted in the exposure of the coring location. An enormous spread of Chenopodiaceae mark the beginning of this phase. As a steppe and desert plant their wide occurrence suggest a very arid phase. However, a local distribution near the lake cannot be excluded. The enlarged shore areas caused by the lake level drop might have been quickly vegetated by Chenopodiaceae like *Atriplex halimus*. Similar to PAZ 3, Cyperaceae and Asteraceae (mainly Liguliflorae) percentages rise. Pollen of *Myriophyllum spicatum* type rapidly increase at the end of PAZ 1. This group of aquatic plants is known to flower under stress conditions like a decreasing lake level (Bottema et al., 2001). The lake level decline suggested by the pollen assemblage agrees well with the lake level reconstruction of the Sea of Galilee (Hazan et al., 2005; Fig. 3.4; cf. Tzedakis, 2007).

Despite new insights into the vegetation and climate of northern Israel during ca. 28 to 22.5 ka BP presented here, answering all open questions on the paleoenvironmental setting of the southern Levant during the Last Glacial is beyond the scope of this article. To solve the apparent conflict of palynological and hydrological investigations, quantitative climate analyses and long, continuous, and well-dated pollen records could help.

3.6 Conclusions

1. The modified chronology reveals a continuous sediment profile of core KIN2 from ca. 28 to 22.5 ka cal BP, the time of a major lake level high stand of the Sea of Galilee.
2. Changes in the pollen assemblage coincide well with changes in the KIN2 lithology and lake level changes of the Sea of Galilee.
3. Pollen of grasses, other herbs, and dwarf shrubs (Poaceae, Chenopodiaceae, *Artemisia*, and other Asteraceae) and deciduous oaks (*Quercus ithaburensis* type) were most abundant in the catchment of the Sea of Galilee during the high stand indicating a dominance of steppe vegetation with some stands of oak woodland.
4. These results disagree with a previous pollen-based hypothesis that assumed the spread of Mediterranean forest during glacial phases. However, the dominance of steppe resembles other results from Eastern Mediterranean palynological studies and therefore supports an overall uniform vegetation in the Eastern Mediterranean.
5. The palynological data from core KIN2 might suggest semiarid and cool conditions. Even drier conditions prevailed during ca. 24 to 22.5 ka cal BP, when the lake level retreated. There is no evidence for increased effective moisture compared to today.
6. There is an apparent conflict between the pollen data that call for relatively dry conditions in the vicinity of the Sea of Galilee during MIS 2 and other lines of regional hydroclimate proxies that call for wetter conditions (e.g., high lake levels, dissolution of carbonates, and enhanced supply of bicarbonate to the lakes), which could be related to a divergence of effective moisture available to plants and total precipitation rates.

3.7 Acknowledgements

We thank the GFZ German Research Centre for Geosciences for providing the sediment samples for the analyses. This study is a contribution to the Helmholtz Association (HGF) climate initiative REKLIM Topic 8 “Rapid climate change derived from proxy data”. We acknowledge Karen Schmeling and Helen Böttcher from the University of Bonn for their technical support. We also thank Laurence Vidal and Dafna Langgut for providing pollen data and Lilach Lev for providing radiocarbon data. This project is affiliated to the CRC 806 “Our way to Europe”. We thank the German Research Foundation (DFG) for funding this project.

3.8 References

Bar-Matthews, M., Ayalon, A., and Kaufman, A.: Late Quaternary Paleoclimate in the Eastern Mediterranean Region from Stable Isotope Analysis of Speleothems at Soreq Cave, Israel, Quaternary Res., 47, 155–168, doi:10.1006/qres.1997.1883, 1997.

Barkan, E., Luz, B., and Lazar, B.: Dynamics of the carbon dioxide system in the Dead Sea, Geochim. Cosmochim. Ac., 65, 355–368, doi:10.1016/S0016-7037(00)00540-8, 2001.

Bartov, Y., Goldstein, S. L., Stein, M., and Enzel, Y.: Catastrophic arid episodes in the Eastern Mediterranean linked with the North Atlantic Heinrich events, Geology, 31, 439–442, doi:10.1130/0091-7613(2003)031<0439:Caeite>2.0.Co;2, 2003.

Baruch, U.: The Late Holocene Vegetational History of Lake Kinneret (Sea of Galilee), Israel, Paléorient, 37–48, doi:10.3406/paleo.1986.4407, 1986.

Begin, Z. B., Ehrlich, A., and Nathan, Y.: Lake Lisan: the Pleistocene precursor of the Dead Sea, Isr. Geol. Surv. Bull, 1–30, 1974.

Ben-Avraham, Z., Rosenthal, M., Tibor, G., Navon, H., Wust-Bloch, H., Hofstetter, R., and Rybakov, M.: Structure and Tectonic Development of the Kinneret Basin, in: Lake Kinneret: Ecology and Management, edited by: Zohary, T., Sukenik, A., Berman, T., and Nishri, A., Aquatic Ecology Series, 6, Springer, Dordrecht, 19–38, 2014.

Berger, A. and Loutre, M. F.: Insolation values for the climate of the last 10 million years, Quaternary Sci. Rev., 10, 297–317, doi:10.1016/0277-3791(91)90033-Q, 1991.

Berman, T., Zohary, T., Nishri, A., and Sukenik, A.: General Background, in: Lake Kinneret: Ecology and Management, edited by: Zohary, T., Sukenik, A., Berman, T., and Nishri, A., Aquatic Ecology Series, 6, Springer, Dordrecht, 1–15, 2014.

Beug, H.-J.: Leitfaden der Pollenbestimmung für Mitteleuropa und angrenzende Gebiete, Verlag Dr. Friedrich Pfeil, München, 2004.

Blaauw, M.: Methods and code for ‘classical’ age-modelling of radiocarbon sequences, Quat. Geochronol., 5, 512–518, doi:10.1016/j.quageo.2010.01.002, 2010.

Bottema, S., Woldring, H., and Kayan, I.: The Late Quarternary Vegetation History of Western Turkey, in: The Ilipinar Excavations II, edited by: Roodenberg, J. J. and Thissen, L. C., Nederlands Instituut voor het Nabije Oosten, Leiden, 327–354, 2001.

Cheddadi, R. and Rossignol-Strick, M.: Eastern Mediterranean Quaternary paleoclimates from pollen and isotope records of marine cores in the Nile Cone Area, Paleoceanography, 10, 291–300, doi:10.1029/94PA02672, 1995.

Chester, P. I. and Raine, J. I.: Pollen and spore keys for Quaternary deposits in the northern Pindos Mountains, Greece, Grana, 40, 299–387, doi:10.1080/00173130152987535, 2001.

Dan, J., Yaalon, D. H., Koyumdjisky, H., and Raz, Z.: The soil association map of Israel (1:1,000,000), Israel J. Earth Sci., 21, 29–49, 1972.

Dayan, U.: Climatology of Back Trajectories from Israel Based on Synoptic Analysis, J. Clim. Appl. Meterol., 25, 591–595, doi:10.1175/1520-0450(1986)025<0591:COBTFI>2.0.CO;2, 1986.

Develle, A. L., Gasse, F., Vidal, L., Williamson, D., Demory, F., Van Campo, E., Ghaleb, B., and Thouveny, N.: A 250 ka sedimentary record from a small karstic lake in the Northern Levant (Yammoûneh, Lebanon): Paleoclimatic implications, Palaeogeogr. Palaeocl., 305, 10–27, doi:10.1016/j.palaeo.2011.02.008, 2011.

Enzel, Y., Amit, R., Dayan, U., Crouvi, O., Kahana, R., Ziv, B., and Sharon, D.: The climatic and physiographic controls of the eastern Mediterranean over the late Pleistocene climates in the southern Levant and its neighboring deserts, Global Planet. Change, 60, 165–192, doi:10.1016/j.gloplacha.2007.02.003, 2008.

Faegri, K. and Iversen, J.: Textbook of Pollen Analysis, 4 Edn., John Wiley &. Sons, Chichester, New York, Brisbane, Toronto, Singapore, 1989.

Fleitmann, D., Cheng, H., Badertscher, S., Edwards, R. L., Mudelsee, M., Göktürk, O. M., Fankhauser, A., Pickering, R., Raible, C. C., Matter, A., Kramers, J., and Tüysüz, O.: Timing and climatic impact of Greenland interstadials recorded in stalagmites from northern Turkey, Geophys. Res. Lett., 36, L19707, doi:10.1029/2009gl040050, 2009.

Frumkin, A., Ford, D. C., and Schwarcz, H. P.: Continental Oxygen Isotopic Record of the Last 170,000 Years in Jerusalem, Quaternary Res., 51, 317–327, doi:10.1006/qres.1998.2031, 1999.

Frumkin, A. and Stein, M.: The Sahara–East Mediterranean dust and climate connection revealed by strontium and uranium isotopes in a Jerusalem speleothem, Earth Planet. Sc. Lett., 217, 451–464, doi:10.1016/S0012-821X(03)00589-2, 2004.

Frumkin, A., Bar-Yosef, O., and Schwarcz, H. P.: Possible paleohydrologic and paleoclimatic effects on hominin migration and occupation of the Levantine Middle Paleolithic, J. Hum. Evol., 60, 437–451, doi:10.1016/j.jhevol.2010.03.010, 2011.

Gasse, F., Vidal, L., Develle, A. L., and Van Campo, E.: Hydrological variability in the Northern Levant: a 250 ka multiproxy record from the Yammoûneh (Lebanon) sedimentary sequence, Clim. Past, 7, 1261–1284, doi:10.5194/cp-7-1261-2011, 2011.

Gasse, F., Vidal, L., Van Campo, E., Demory, F., Develle, A.-L., Tachikawa, K., Elias, A., Bard, E., Garcia, M., Sonzogni, C., and Thouveny, N.: Hydroclimatic changes in northern Levant over the past 400,000 years, Quaternary Sci. Rev., 111, 1–8, doi:10.1016/j.quascirev.2014.12.019, 2015.

Greenbaum, N., Ben-Zvi, A., Haviv, I., and Enzel, Y.: The hydrology and paleohydrology of the Dead Sea tributaries, in: New frontiers in Dead Sea paleoenvironmental research, edited by: Enzel, Y., Agnon, A., and Stein, M., Geological Society of America, Boulder, 63–93, 2006.

Grimm, E. C.: CONISS: a FORTRAN 77 program for stratigraphically constrained cluster analysis by the method of incremental sum of squares, Comput. Geosci., 13, 13–35, doi:10.1016/0098-3004(87)90022-7, 1987.

Haliva-Cohen, A., Stein, M., Goldstein, S. L., Sandler, A., and Starinsky, A.: Sources and transport routes of fine detritus material to the Late Quaternary Dead Sea basin, Quaternary Sci. Rev., 50, 55–70, doi:10.1016/j.quascirev.2012.06.014, 2012.

Hazan, N., Stein, M., Agnon, A., Marco, S., Nadel, D., Negendank, J. F. W., Schwab, M. J., and Neev, D.: The late Quaternary limnological history of Lake Kinneret (Sea of Galilee), Israel, Quaternary Res., 63, 60–77, doi:10.1016/j.yqres.2004.09.004, 2005.

Horowitz, A.: Climatic and vegetational developments in northeastern Israel during Upper Pleistocene-Holocene times, Pollen et Spores, 13, 255–278, 1971.

Horowitz, A.: The Quarternary of Israel, Academic Press, New York, London, 1979.

Horowitz, A.: Palynology of arid lands, Elsevier, Amsterdam, 1992.

Katz, A., Kolodny, Y., and Nissenbaum, A.: The geochemical evolution of the Pleistocene Lake Lisan-Dead Sea system, Geochim. Cosmochim. Ac., 41, 1609–1626, doi:10.1016/0016-7037(77)90172-7, 1977.

Kolodny, Y., Stein, M., and Machlus, M.: Sea-rain-lake relation in the Last Glacial East Mediterranean revealed by $\delta^{18}O$-$\delta^{13}C$ in Lake Lisan aragonites, Geochim. Cosmochim. Ac., 69, 4045–4060, doi:10.1016/j.gca.2004.11.022, 2005.

Langgut, D., Almogi-Labin, A., Bar-Matthews, M., and Weinstein-Evron, M.: Vegetation and climate changes in the South Eastern Mediterranean during the Last Glacial-Interglacial cycle (86 ka):

new marine pollen record, Quaternary Sci. Rev., 30, 3960–3972, doi:10.1016/j.quascirev.2011.10.016, 2011.

Langgut, D., Finkelstein, I., and Litt, T.: Climate and the Late Bronze Collapse: New Evidence from the Southern Levant, Tel Aviv, 40, 149–175, doi:10.1179/033443513X13753505864205, 2013.

Langgut, D., Finkelstein, I., Litt, T., Neumann, F. H., and Stein, M.: Vegetation and Climate Changes during the Bronze and Iron Ages (~3600–600 BCE) in the Southern Levant Based on Palynological Records, Radiocarbon, 57, 217–235, doi:10.2458/azu_rc.57.18555, 2015.

Lev, L., Boaretto, E., Heller, J., Marco, S., and Stein, M.: The feasibility of using Melanopsis shells as radiocarbon chronometers, Lake Kinneret, Israel, Radiocarbon, 49, 1003–1015, doi:10.1017/S0033822200042867, 2007.

Lev, L.: Paleo-hydrology and paleo-limnology of Lake Kinneret during the late Quaternary from lake sediments and carbonate shells, Dissertation, Tel Aviv University, Tel Aviv, 151 pp., 2014.

Lisiecki, L. E. and Raymo, M. E.: A Pliocene-Pleistocene stack of 57 globally distributed benthic $\delta^{18}O$ records, Paleoceanography, 20, PA1003, doi:10.1029/2004PA001071, 2005.

Machlus, M., Enzel, Y., Goldstein, S. L., Marco, S., and Stein, M.: Reconstructing low levels of Lake Lisan by correlating fan-delta and lacustrine deposits, Quatern. Int., 73–74, 137–144, doi:10.1016/S1040-6182(00)00070-7, 2000.

Miebach, A., Niestrath, P., Roeser, P., and Litt, T.: Impacts of climate and humans on the vegetation in northwestern Turkey: palynological insights from Lake Iznik since the Last Glacial, Clim. Past, 12, 575–593, doi:10.5194/cp-12-575-2016, 2016.

Mix, A. C., Bard, E., and Schneider, R.: Environmental processes of the ice age: land, oceans, glaciers (EPILOG), Quaternary Sci. Rev., 20, 627–657, doi:10.1016/S0277-3791(00)00145-1, 2001.

Moore, P. D., Webb, J. A., and Collinson, M. E.: Pollen analysis, 2 Edn., Blackwell Scientific Publications, Oxford, 1991.

Nadel, D.: Ohalo II: a preliminary report, Mitekufat Haeven: Journal of the Israel Prehistoric Society, 23, 48–59, 1990.

Nadel, D., Carmi, I., and Segal, D.: Radiocarbon dating of Ohalo II: Archaeological and methodological implications, J. Archaeol. Sci., 22, 811–822, doi:10.1016/0305-4403(95)90010-1, 1995.

Neumann, F., Schölzel, C., Litt, T., Hense, A., and Stein, M.: Holocene vegetation and climate history of the northern Golan heights (Near East), Veget. Hist. Archaeobot., 16, 329–346, doi:10.1007/s00334-006-0046-x, 2007.

Pickarski, N., Kwiecien, O., Langgut, D., and Litt, T.: Abrupt climate and vegetation variability of eastern Anatolia during the last glacial, Clim. Past, 11, 1491–1505, doi:10.5194/cp-11-1491-2015, 2015.

Reille, M.: Pollen et spores d'Europe et d'Afrique du Nord: supplement 1, Laboratoire de Botanique Historique et Palynologie, Marseille, 1995.

Reille, M.: Pollen et spores d'Europe et d'Afrique du Nord: supplement 2, Laboratoire de Botanique Historique et Palynologie, Marseille, 1998.

Reille, M.: Pollen et spores d'Europe et d'Afrique du Nord, 2 Edn., Laboratoire de Botanique Historique et Palynologie, Marseille, 1999.

Reimer, P. J., Bard, E., Bayliss, A., Beck, J. W., Blackwell, P. G., Ramsey, C. B., Buck, C. E., Cheng, H., Edwards, R. L., Friedrich, M., Grootes, P. M., Guilderson, T. P., Haflidason, H., Hajdas, I., Hatte, C., Heaton, T. J., Hoffmann, D. L., Hogg, A. G., Hughen, K. A., Kaiser, K. F., Kromer, B., Manning, S. W., Niu, M., Reimer, R. W., Richards, D. A., Scott, E. M., Southon, J. R., Staff, R. A., Turney, C. S. M., and van der Plicht, J.: Intcal13 and Marine13 Radiocarbon Age Calibration Curves 0-50,000 Years Cal BP, Radiocarbon, 55, 1869–1887, doi:10.2458/azu_js_rc.55.16947, 2013.

Richter, J., Hauck, T., Vogelsang, R., Widlok, T., Le Tensorer, J.-M., and Schmid, P.: "Contextual areas" of early Homo sapiens and their significance for human dispersal from Africa into Eurasia between 200 ka and 70 ka, Quatern. Int., 274, 5–24, doi:10.1016/j.quaint.2012.04.017, 2012.

Robinson, S. A., Black, S., Sellwood, B. W., and Valdes, P. J.: A review of palaeoclimates and palaeoenvironments in the Levant and Eastern Mediterranean from 25,000 to 5000 years BP: setting the environmental background for the evolution of human civilisation, Quaternary Sci. Rev., 25, 1517–1541, doi:10.1016/j.quascirev.2006.02.006, 2006.

Rossignol-Strick, M.: Sea-land correlation of pollen records in the eastern Mediterranean for the glacial-interglacial transition, Quaternary Sci. Rev., 14, 893–915, doi:10.1016/0277-3791(95)00070-4, 1995.

Rozenbaum, A. G.: Tufa deposits in Bet She'an Valley – tectonic and geochronological implications, Master thesis, The Hebrew University of Jerusalem, Jerusalem, 165 pp., 2009.

Sadori, L., Koutsodendris, A., Panagiotopoulos, K., Masi, A., Bertini, A., Combourieu-Nebout, N., Francke, A., Kouli, K., Joannin, S., Mercuri, A. M., Peyron, O., Torri, P., Wagner, B., Zanchetta, G., Sinopoli, G., and Donders, T. H.: Pollen-based paleoenvironmental and paleoclimatic change at Lake Ohrid (south-eastern Europe) during the past 500 ka, Biogeosciences, 13, 1423–1437, doi:10.5194/bg-13-1423-2016, 2016.

Schiebel, V.: Vegetation and climate history of the southern levant during the last 30,000 years based on palynological investigation, Dissertation, Rheinische Friedrich-Wilhelms-Universität Bonn, Bonn, 104 pp., 2013.

Sneh, A., Bartov, Y., Weissbrod, T., and Rosensaft, M.: Geological Map of Israel, 1:200,000. Isr. Geol. Surv. (4 sheets), 1998.

Stein, M., Starinsky, A., Katz, A., Goldstein, S. L., Machlus, M., and Schramm, A.: Strontium isotopic, chemical, and sedimentological evidence for the evolution of Lake Lisan and the Dead Sea, Geochim. Cosmochim. Ac., 61, 3975–3992, doi:10.1016/S0016-7037(97)00191-9, 1997.

Stein, M.: Late Quaternary Limnological History of Lake Kinneret, in: Lake Kinneret: Ecology and Management, edited by: Zohary, T., Sukenik, A., Berman, T., and Nishri, A., Aquatic Ecology Series, 6, Springer, Dordrecht, 39–58, 2014.

Stiller, M., Rosenbaum, J. M., and Nishri, A.: The origin of brines underlying Lake Kinneret, Chem. Geol., 262, 293–309, doi:10.1016/j.chemgeo.2009.01.030, 2009.

Stockhecke, M., Timmermann, A., Kipfer, R., Haug, G. H., Kwiecien, O., Friedrich, T., Menviel, L., Litt, T., Pickarski, N., and Anselmetti, F. S.: Millennial to orbital-scale variations of drought intensity in the Eastern Mediterranean, Quaternary Sci. Rev., 133, 77–95, doi:10.1016/j.quascirev.2015.12.016, 2016.

Stockmarr, J.: Tablets with spores used in absolute pollen analysis, Pollen et Spores, 13, 615–621, 1971.

Torfstein, A., Goldstein, S. L., Stein, M., and Enzel, Y.: Impacts of abrupt climate changes in the Levant from Last Glacial Dead Sea levels, Quaternary Sci. Rev., 69, 1–7, doi:10.1016/j.quascirev.2013.02.015, 2013.

Tzedakis, P. C.: Seven ambiguities in the Mediterranean palaeoenvironmental narrative, Quaternary Sci. Rev., 26, 2042–2066, doi:10.1016/j.quascirev.2007.03.014, 2007.

Vaks, A., Bar-Matthews, M., Ayalon, A., Schilman, B., Gilmour, M., Hawkesworth, C. J., Frumkin, A., Kaufman, A., and Matthews, A.: Paleoclimate reconstruction based on the timing of speleothem growth and oxygen and carbon isotope composition in a cave located in the rain shadow in Israel, Quaternary Res., 59, 182–193, doi:10.1016/S0033-5894(03)00013-9, 2003.

Vaks, A., Bar-Matthews, M., Ayalon, A., Matthews, A., Frumkin, A., Dayan, U., Halicz, L., Almogi-Labin, A., and Schilman, B.: Paleoclimate and location of the border between Mediterranean climate region and the Saharo–Arabian Desert as revealed by speleothems from the northern Negev Desert, Israel, Earth Planet. Sc. Lett., 249, 384–399, doi:10.1016/j.epsl.2006.07.009, 2006.

van Zeist, W., Baruch, U., and Bottema, S.: Holocene palaeoecology of the Hula area, northeastern Israel, in: A timeless vale. Archaeological and related essays on the Jordan Valley in honour of Gerrit van der Kooij on the occasion of his sixty-fifth birthday, edited by: Kaptijnand, E. and Petit, L. P., Archaeological Studies Leiden University, Leiden University Press, Leiden, 29–64, 2009.

van Zeist, W. and Bottema, S.: A palynological study of the Acheulian site of Gesher Benot Ya’aqov, Israel, Veget. Hist. Archaeobot., 18, 105–121, doi:10.1007/s00334-008-0167-5, 2009.

Weinstein, M.: The Late Pleistocene vegetation and climate of the northern Golan, Pollen et Spores, 17, 553–562, 1976.

Zaarur, S., Affek, H. P., and Stein, M.: Last glacial-Holocene temperatures and hydrology of the Sea of Galilee and Hula Valley from clumped isotopes in Melanopsis shells, Geochim. Cosmochim. Ac., 179, 142–155, doi:10.1016/j.gca.2015.12.034, 2016.

Ziv, B., Shilo, E., Lechinsky, Y., and Rimmer, A.: Meterology, in: Lake Kinneret: Ecology and Management, edited by: Zohary, T., Sukenik, A., Berman, T., and Nishri, A., Aquatic Ecology Series, 6, Springer, Dordrecht, 81–96, 2014.

Zohary, M.: Plant Life of Palestine: Israel and Jordan, The Ronald Press Company, New York, 1962.

Zohary, T. and Gasith, A.: The Littoral Zone, in: Lake Kinneret: Ecology and Management, edited by: Zohary, T., Sukenik, A., Berman, T., and Nishri, A., Aquatic Ecology Series, 6, Springer, Dordrecht, 517–532, 2014.

4 Last Glacial and early Holocene vegetation, climate, and fire history of the Dead Sea region inferred from palynological analyses

4.1 Abstract

Here, I present a new palynological study inferred from sediments of Lake Lisan, the Last Glacial precursor of the Dead Sea, and the early Holocene Dead Sea. The sediments were recovered from the center of the modern Dead Sea. The study provides pollen data revealing the regional vegetation history, microscopic charcoal data to reconstruct the fire activity, and other palynomorph data such as freshwater and erosion indicators. The palynological results suggest that Irano-Turanian steppe and Saharo-Arabian desert vegetation prevailed in the Dead Sea region during the investigated period (ca. 88,000–9,000 years BP). Nevertheless, Mediterranean woodland elements significantly contributed to the vegetation composition during most of the investigated period suggesting moderate amounts of available water for plants. Since the Lateglacial, the Dead Sea region witnessed several rapid changes in its environmental conditions. Phases with considerably reduced woodland density, increased fire activity, and enhanced catchment erosion occurred. Although climatic triggers are possible, overall increasing human influences in the region make anthropogenic causes probable. The study gains new insights into environmental responses of the Dead Sea region to climate variations in the past. It contributes towards our understanding of paleoenvironmental conditions in the southern Levant, which functioned as a corridor for human migration processes.

4.2 Introduction

The study of the paleoclimate and its influences on environments is essential to understand current and future climate changes (Masson-Delmotte et al., 2013). Revealing the paleoclimate is particularly important for regions vulnerable to climate changes such as the Eastern Mediterranean (Lelieveld et al., 2012). The knowledge of past environments is also crucial for detailed reconstructions of the history of mankind. The Levant in the southeastern Mediterranean region is a possible meeting point of modern humans and Neanderthals, where gene flow between both hominins might have occurred (Kuhlwilm et al., 2016). The southern Levantine fossil record does not only provide evidence for the first migration of modern humans out of Africa (Richter et al., 2012 and references therein) but also for later hominin migration processes towards Eurasia (Mellars, 2011) including the spread of agriculture and husbandry (Miller, 1991). Therefore, the southern Levant is a key area to investigate environmental conditions in the past.

In this sense, the Last Glacial and the early Holocene are particularly interesting to investigate for three reasons. Firstly, a secondary migration of anatomically modern humans (AMHs) out of Africa and the extinction of Neanderthals occurred during the Last Glacial. Skeletal material from Manot Cave, Israel, dated to ca. 55 ka BP (kilo years before present; all radiocarbon dates in this chapter have been calibrated) provides the earliest fossil evidence of a second colonization of the Near East by AMHs (Hershkovitz et al., 2015). AMHs migrated via the Levant towards Eurasia within this second colonization phase (Mellars, 2011). Neanderthals became extinct between 45 and 30 ka BP leading to ongoing discussions about the causes (Shea, 2008). Among others, climatic causes were postulated for AMH migration and Neanderthal extinction processes (e.g., Shea, 2008; Müller et al., 2011).

Secondly, there are ongoing discussions on the hydroclimatic conditions in the southern Levant during the Last Glacial. While the majority of climate records from the Eastern Mediterranean agree on cold and arid conditions during the Last Glacial (e.g., Fleitmann et al., 2009; Langgut et al., 2011; Müller et al., 2011; Pickarski et al., 2015), most studies from the Dead Sea region suggest more humid conditions compared to today. Indications for an increased glacial wetness were provided by various studies that dealt for instance with lake level reconstructions, geochemical compositions of sediments, and speleothem activities. Lake level reconstructions of Lake Lisan, the precursor of the Dead Sea, indicated major lake level high stands during the Last Glacial of up to ca. 240 m above typical Holocene levels (e.g., Bartov et al., 2002; Torfstein et al., 2013b). During the highest stands, Lake Lisan even merged with the Sea of Galilee (Bartov et al., 2003; Hazan et al., 2005; Torfstein et al., 2013b), which is today more than 100 km away. The sediments that deposited during the occurrence of Lake Lisan are mainly comprised of aragonite-detritus laminae (Begin et al., 1974; Katz et al., 1977; Machlus et al., 2000). Aragonite formation required an increased input of freshwater to the lake to provide bicarbonate to the Ca-chloride brine (Stein et al., 1997; Barkan et al., 2001). Therefore, the high lake levels and aragonite deposition indicate increased precipitation rates during the Last Glacial (Stein et al., 1997; Torfstein et al., 2013b). An increased glacial wetness is also suggested by the deposition of speleothems in areas that were too dry for speleothem growth during the Holocene (Vaks et al., 2003, 2006).

Thirdly, the southern Levantine neolithization process including the origin of agriculture, pastoralism, and sedentary village life took place during the early Holocene. Plants such as cereals and pulses were cultivated, and animals such as sheep and goat were domesticated (Kuijt and Goring-Morris, 2002; Shea, 2013). Changes of environmental conditions were among the proposed causes of neolitization processes (Goring-Morris and Belfer-Cohen, 1998; Yasuda et al., 2000). On the other hand, human considerably changed their environment themselves for instance by forest clearance and pastoralism (Miller, 1991; Rollefson and Köhler-Rollefson, 1992).

Despite its outstanding role in terms of archaeology and paleoclimate, little is known about the detailed framework of paleovegetational conditions in the southern Levant during the Last Glacial and early Holocene. The study of fossil pollen and other palynomorphs contained in sediments enables the reconstruction of past environments, particularly the paleovegetation and paleoclimate (Faegri and Iversen, 1989). However, a detailed palynological study based on an independent chronology was still missing for the Dead Sea region during the Last Glacial and Pleistocene-Holocene transition.

Previous palynological studies from the Levant were either based on marine or terrestrial sediments. Marine studies were conducted in the Levantine Basin (Cheddadi and Rossignol-Strick, 1995; Langgut et al., 2011) and suggested cold and dry glacial conditions. However, the pollen assemblages reflect a huge pollen source area given the basin size and were influenced by African vegetation due to the Nile outflow. A terrestrial pollen record encompassing the whole Last Glacial was obtained from Yammouneh Valley, Lebanon (Gasse et al., 2011, 2015). This study also indicated warm and wet interglacials and cold and dry glacials. However, given the high altitude of the Yammouneh Valley, the vegetation might have been influenced by water deficiencies due to water storage as ice or frozen soils (Develle et al., 2011). The same topographic effect might have affected the Birkat Ram area at the Golan

Heights, northern Israel, where palynological results for the last 30 ka suggested a similar vegetation pattern (Schiebel, 2013). Pollen records from Hula Basin, northern Israel, might also encompass large parts or even the whole Last Glacial period (e.g., Horowitz, 1979; Weinstein-Evron, 1983). However, problems with radiocarbon (^{14}C) dating (e.g., Meadows, 2005; van Zeist et al., 2009) and Uranium-Thorium (U-Th) dating (Weinstein-Evron et al., 2001) of sediment cores from Hula Basin make a convincing correlation to other records difficult. Major chronological uncertainties do also occur in a sediment core from Ghab Valley, northwestern Syria. The pollen sequence suggests the spread of Mediterranean forests during marine isotope stage (MIS) 3 and 2 (Niklewski and Van Zeist, 1970). However, Rossignol-Strick (1995) revised the chronology to a Lateglacial and Holocene age. Horowitz (1992) presented a vegetation model for the Dead Sea region during the Late Quaternary based on several low-resolution pollen sequences. The correlation to climate records was based on few datings and the following hypothesis: during times corresponding to even numbered MIS, woodland vegetation predominated (e.g., MIS 4 and 2), while periods corresponding to odd numbered MIS were characterized by the dominance of steppe vegetation (e.g., MIS 3 and 1) and/or desert vegetation (e.g., MIS 5 and 1).

The study of microscopic charcoal can provide valuable insights into the history of fire activity and the relationship between the paleovegetation, anthropogenic activities, and fire regimes (Whitlock and Larsen, 2001). However, almost none of the Last Glacial and early Holocene palynological studies from the Levant investigated microscopic charcoal in addition to pollen. Exceptions are studies from Ghab Valley (Yasuda et al., 2000) and Hula Basin (Turner et al., 2010) dating to the Lateglacial and Holocene. However, large uncertainties in their radiocarbon chronologies (e.g., Meadows, 2005; van Zeist et al., 2009) make the timing of events and correlation to other records speculative. Still, these records provide comparisons between changes in fire activity and vegetation because charcoal and pollen originated from the same sediment sequences. The fire history during earlier times of the Last Glacial and particularly at the Dead Sea remained unknown.

Here, I present a palynological study inferred from sediments of the Last Glacial Lake Lisan (Lisan Formation) and the early Holocene Dead Sea (Zeelim Formation) connecting to a detailed Holocene pollen record from Ein Gedi, western Dead Sea shore (Litt et al., 2012). The investigated sediments originate from a sediment core drilled at the central Dead Sea with an independent chronology (Neugebauer et al., 2014; Torfstein et al., 2015). The palynological study provides new insights into the vegetation and fire history in the southern Levant in relation to climate changes and anthropogenic influences. It tests previous hypotheses concerning the paleovegetation in the Dead Sea region during the Last Glacial.

4.3 Study area

4.3.1 Dead Sea

The Dead Sea is situated in the southern Levant bordering Israel, Jordan, and the Palestinian territory West Bank (Fig. 4.1). It is a terminal lake and is primarily fed by the perennial Jordan River but also by groundwater and several streams, which are mainly ephemeral, i.e. they experience occasional

Figure 4.1: Topography of the southern Levant with Dead Sea drainage and maximum extent of Lake Lisan after Greenbaum et al. (2006).

flashfloods. The total drainage area comprises 42,200 km² (Greenbaum et al., 2006). The Dead Sea occupies the lowest continental depression on the Earth (currently ca. 430 m below mean sea level (m bmsl)). With a surface area of about 760 km² (76 km in N-S direction, up to 17 km in W-E direction), it is the largest lake in the region (Litt et al., 2012). A sill separates a northern deep basin with a water depth of about 300 m from a shallower southern basin. While the water depth of the northern basin steadily declined during the last decades due to human impact, the southern basin is nowadays occupied by evaporation ponds (Greenbaum et al., 2006). The Dead Sea is a hypersaline water body with a salinity of ca. 27.5 % (ca. 340 g/l), i.e. the salinity is multiple times higher compared to seawater (Gavrieli and Stein, 2006).

The Dead Sea is located at the Dead Sea Transform, a tectonic boundary between the African Plate and the Anatolian Plate. The Dead Sea Basin is the largest and oldest of several pull-apart basins, which originated along the transform during the plate motion process (Garfunkel, 1981, 1997). Since its formation in the early Miocene, the Dead Sea Basin subsided continuously and acted as a major sediment trap (Garfunkel, 1997). During the late Neogene, the valley was filled with water coming from the Mediterranean Sea and forming the marine Sedom lagoon (Stein, 2014). After the disconnection of the Sedom lagoon from the Mediterranean Sea, the Dead Sea Basin was occupied by a series of lakes. One of them was Lake Lisan, which occurred during the Last Glacial. While chronostratigraphic analyses at the shore indicate an age of ca. 70 to 15 ka BP for the duration of Lake Lisan (e.g., Torfstein et al., 2013a), a new core drilled at the deepest part of the Dead Sea suggest that the transition to Lake Lisan occurred ca. 15–20 ka earlier (Torfstein et al., 2015; Neugebauer et al., 2016).

4.3.2 Climate and vegetation

The southern Levant is a transition zone of different climate regimes (Fig. 4.2). The northern part is characterized by Mediterranean climate with hot, dry summers and mild, wet winters. The precipitation is mainly brought by Cyprus Lows, i.e. Eastern Mediterranean mid latitude cyclones (Enzel et al., 2003). The southern part is occupied by a dry, subtropical desert (Horowitz, 1979). Here, precipitation arrives mainly as flash floods by the tropical Active Red Sea Trough (Dayan and Morin, 2006). While precipitations generally decrease towards the south and with lower elevations, temperatures generally decrease towards the north and with higher elevations. Seasonality increases towards the east (Goldreich, 2003). The Dead Sea itself lies in a hyperarid area with 50–100 mm mean annual precipitation (Greenbaum et al., 2006).

The natural vegetation of the southern Levant is primarily shaped by the precipitation distribution but also by temperatures and soils (Zohary, 1962, 1982; Danin and Plitmann, 1987; Danin, 1992; Fig. 4.2). The northern part is characterized by the Mediterranean biome with arboreal climax communities. Mediterranean woodland reaches southward to the Judean Mountains and along the upper slopes of the rift valley east of the Dead Sea (Zohary, 1962). Common trees are *Quercus* spp., *Pistacia* spp., *Ziziphus* spp., *Rhamnus* spp., *Ceratonia siliqua, Phillyrea latifolia, Styrax officinalis*, *Arbutus andrachne*, and several Rosaceae species. They are accompanied by conifers such as *Pinus halepensis* and *Juniperus* spp. (Baruch, 1986 and references therein; Danin, 1992). Irano-Turanian steppe occupies areas with ca. 100–350 mm mean annual precipitation. It is characterized by herb and dwarf-shrub communities dominated by *Artemisia herba-alba.* Saharo-Arabian desert vegetation occurs in the southern part, where mean annual precipitation falls below 100 mm. It is a vegetation type with sparse plant cover and low diversity. Important representatives of the Saharo-Arabian vegetation are Chenopodiaceae/ Amaranthaceae. Sudanian vegetation occupies tropical oases of the Jordan Valley. Mainly trees and shrubs such as *Maerua crassifolia, Acacia tortilis, Balanites aegyptiaca*, and *Ziziphus spina-christi* compose this vegetation type (Zohary, 1962).

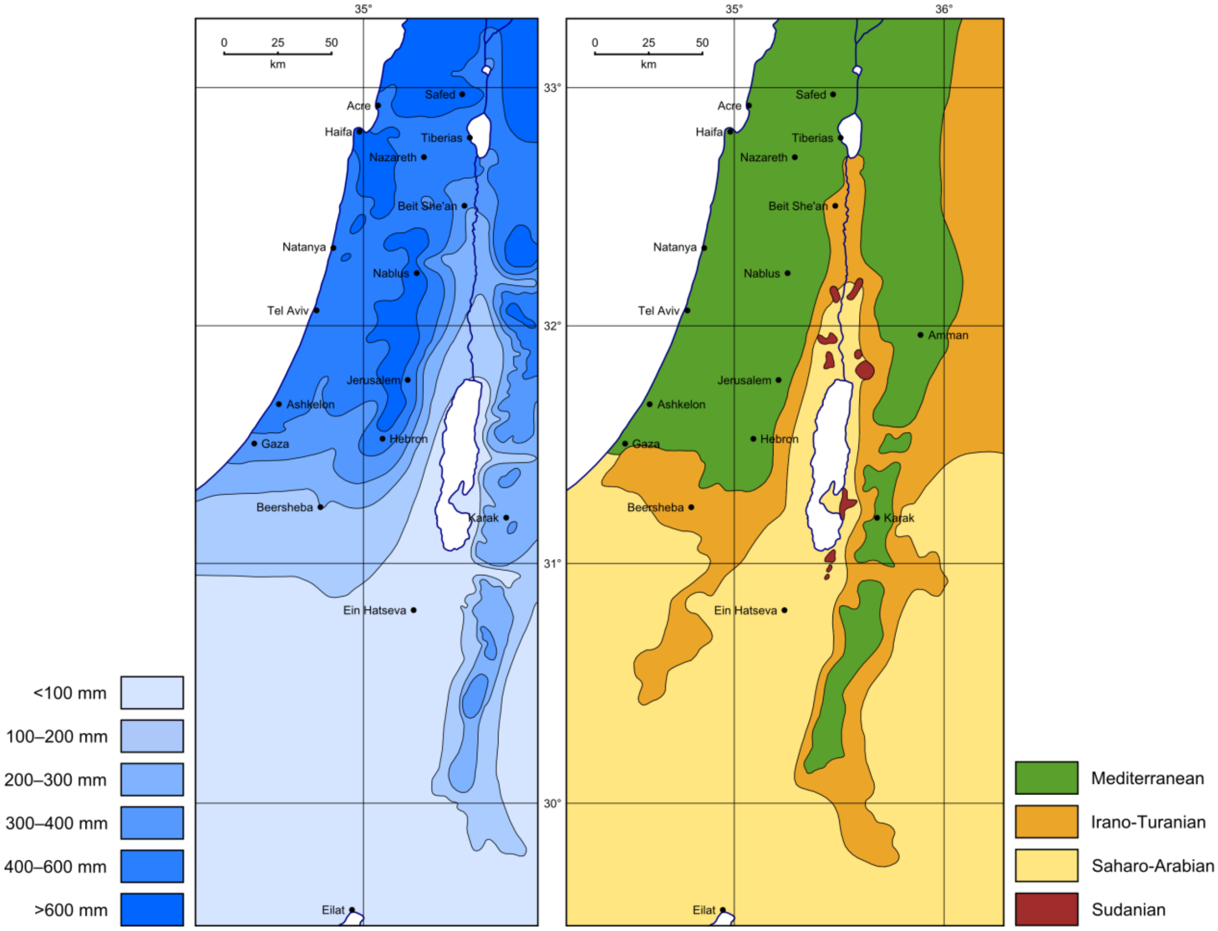


Figure 4.2: Mean annual precipitation and plantgeographical territories of the southern Levant after Zohary (1962).

4.4 Material and methods

The Dead Sea Deep Drilling Project (DSDDP) under the auspices of the International Continental Scientific Drilling Program (ICDP) was intended to gain the first long, continuous, and high-resolution sediment core from the Dead Sea. The drilling campaign took place in 2010/2011 (Stein et al., 2011a, b). I analyzed sediment samples from site 5017-1, which is located at the center of the northern basin (Fig. 4.1). While most samples were taken from core 5017-1-A, some originated from core 5017-1-H according to the composite profile for site 5017-1 described in Neugebauer et al. (2014). The sediment depth of the analyzed samples span from 199 to 63 m composite depth. The investigated interval encompasses the Lisan Formation and the lower Zeelim Formation (Neugebauer et al., 2014, 2016). Disturbed, slumped, and homogenous sediment sequences were not sampled resulting in sampling gaps of different length.

The current chronology of the investigated sediment sequence is based on ^{14}C and U-Th dating (Table 4.1). Eight ^{14}C dates were conducted from terrestrial plant remains. ^{14}C dates were calibrated using the calibration dataset IntCal13 (Reimer et al., 2013) within the software OxCal 4.2 (Ramsey, 2009). More details are described by Neugebauer et al. (2014). U-Th dating was performed on six samples of primary aragonite (for more details see Torfstein et al., 2015). In addition, Neugebauer et al. (2014) and Torfstein et al. (2015) correlated deposits of massive gypsum in core 5017-1 to U-Th dated counterparts in the exposed margins of the Dead Sea Basin (Torfstein et al., 2013a). According to the interpolation of these dates, the investigated sediment sequence for pollen analysis encompasses ca. 88–9 ka BP.

Table 4.1: Radiocarbon (^{14}C) and Uranium-Thorium (U-Th) dates of the Dead Sea core 5017-1 with composite depths. The median and range of calibrated ages are given for ^{14}C dates (Neugebauer et al., 2014). AMS: accelerator mass spectroscopy.

Depth (m)	Age	Technique	Source
60.11	8,348±57 a cal BP	AMS ^{14}C of terrestrial plant remains	Neugebauer et al., 2014
89.25	11,440±119 a cal BP	AMS ^{14}C of terrestrial plant remains	Neugebauer et al., 2014
92.06	14,145±115 a cal BP	AMS ^{14}C of terrestrial plant remains	Neugebauer et al., 2014
92.20	14,067±363 a BP	U-Th	Torfstein et al., 2015
96	14,500±500 a BP	Correlated U-T[1]	Neugebauer et al., 2014 (depth) Torfstein et al., 2013a (age)
99	15,500±500 a BP	Correlated U-Th[1]	Neugebauer et al., 2014 (depth) Torfstein et al., 2013a (age)
101	17,100±500 a BP	Correlated U-Th[1]	Neugebauer et al., 2014 (depth) Torfstein et al., 2013a (age)
102.10	18,140±45 a BP	U-Th	Torfstein et al., 2015
108.51	20,942±131 a cal BP	AMS ^{14}C of terrestrial plant remains	Neugebauer et al., 2014
115.37	30,340±261 a cal BP	AMS ^{14}C of terrestrial plant remains	Neugebauer et al., 2014
139.27	41,799±935 a BP	U-Th	Torfstein et al., 2015
139.60	43,946±717 a cal BP	AMS ^{14}C of terrestrial plant remains	Neugebauer et al., 2014
144.5	46,000±1700 a BP	Correlated U-Th[1]	Torfstein et al., 2015 modified after Torfstein et al., 2013a
157.94	55,864±5627 a cal BP	AMS ^{14}C of terrestrial plant remains[2]	Neugebauer et al., 2014
174.52	70,513±4926 a BP	U-Th	Torfstein et al., 2015
193.58	85,557±8176 a BP	U-Th	Torfstein et al., 2015
220.03–222.91	95,446±6481 a BP	U-Th	Torfstein et al., 2015

[1] massive gypsum units of core 5017-1 were correlated to U-Th dated counterparts in the exposed margins of the Dead Sea Basin

[2] sample is out of the IntCal13 calibration range and needs to be considered with caution

Pollen preparation was conducted following a standard protocol described by Faegri and Iversen (1989). The sample volume varied between 2.5–6 cm³ for laminated sediment samples and massive gypsum samples and 7.5–37 cm³ for halite samples. Halite samples were dissolved in water prior to the chemical treatment. The chemical treatment included 10 % hot hydrochloric acid (HCl; 10 minutes), 40 % hydrofluoric acid (HF; at least 48 hours), 10 % hot HCl (10 minutes), glacial acetic acid ($C_2H_4O_2$), hot acetolysis with 1 part concentrated sulfuric acid (H_2SO_4) and 9 parts concentrated acetic anhydrite ($C_4H_6O_3$; max. 3 minutes), and $C_2H_4O_2$. Sieving and ultrasonic sieving were carried out to remove coarser particles than 200 µm and finer particles than 10 µm, respectively. *Lycopodium* tablets with a known number of spores were added to each sample to calculate pollen, NPP (non-pollen palynomorph), and microscopic charcoal concentrations (Stockmarr, 1971). Samples were preserved in glycerol and were stained with safranin.

Palynomorphs were identified with a Zeiss Axio Lab.A1 light microscope with the help of palynomorph atlases and keys (Reille, 1995, 1998, 1999; Beug, 2004) as well as the pollen reference collection of the Steinmann Institute, University of Bonn. At least 500 terrestrial pollen grains were counted in each sample. Obligate aquatic plants were excluded from the total pollen sum to exclude local taxa growing in the lake (Moore et al., 1991). Furthermore, destroyed and unknown pollen were excluded from the total pollen sum, which was used to calculate percentages of the pollen assemblage. Charcoal particles were divided into two size fractions with diameters of 25–100 µm and 100–200 µm. If the size fraction is not stated hereafter, the sum of both fractions is given.

Multivariate numerical statistics were applied to display, summarize, and interpret the pollen data. Firstly, a stratigraphically constrained cluster analysis using a square root transformation was performed by CONISS (Grimm, 1987) within the software Tilia. All taxa with more than 2 % of the total pollen sum and the sum of trees and shrubs were used for the analysis. Secondly, a principal component analysis (PCA) with a square root transformation scaling was performed in R using the package vegan (Oksanen et al., 2016). All taxa with more than 2 % of the total pollen sum and charcoal percentages (based on the total pollen sum) were used for the analysis. In addition, linear regression analyses were conducted with Microsoft Excel 2013 to evaluate the relationship between charcoal and single pollen taxa. Boxplots were drawn with Microsoft Excel 2013 to illustrate the variance of pollen concentrations in different sediment types.

4.5 Results and discussion

4.5.1 Pollen zonation and pollen concentration

The results of the palynological investigation are summarized in Fig. 4.3–4.9 and Table 4.2. Five pollen assemblage zones (PAZs) were defined according to the cluster analysis (Fig. 4.5). PAZs were further grouped into two pollen assemblage superzones (PASs) for a better overview of future synthesis pollen records from the whole Dead Sea core 5017-1. The PCA biplot illustrates the variation among samples of defined pollen zones (Fig. 4.3). While samples of PAS I, PAZ II2, PAZ II3, and PAZ II4 cluster together, respectively, samples of PAZ II1 are less similar and are scattered between the other clusters. The cluster analysis and the PCA indicate that PAZ II2 and II3 are the closest related pollen zones.

Table 4.2: Pollen assemblage superzones (PASs) and pollen assemblage zones (PAZs) with composite depths, ages (linear interpolation between ages shown in Table 4.1), main components of pollen assemblages (arboreal pollen (AP) and non-arboreal pollen (NAP) with mean percentages), and definition of lower boundaries (LB).

PAS	PAZ	Depth (m)	Age (ka BP)	Pollen assemblage	
I	Not defined	63.2–75.8	8.7–10.0	AP:	*Quercus ithaburensis* type (6.6 %), *Juniperus* type (1 %).
				NAP:	Chenopodiaceae (43.4 %), Poaceae (11 %), Liguliflorae (7.3 %), Tubuliflorae (5.1 %), *Artemisia* (3.7 %), *Plantago* (3.9 %), Scrophulariaceae (3.1 %), *Rumex* (2.7 %), Cerealia type (2.3 %), Brassicaceae (2 %), Apiaceae (1.6 %).
				LB:	Increase of Chenopodiaceae, Liguliflorae, *Plantago*, Scrophulariaceae, Tubuliflorae, *Rumex*; Decrease of *Artemisia*, *Quercus ithaburensis* type, *Juniperus* type, *Quercus calliprinos* type.
II	II1	75.8–96.0	10.0–14.5	AP:	*Quercus ithaburensis* type (14.8 %), *Juniperus* type (1.8 %), *Pistacia* (1 %).
				NAP:	Chenopodiaceae (33.4 %), Poaceae (14.4 %), *Artemisia* (9.5 %), Tubuliflorae (4.2 %), *Rumex* (2.8 %), *Plantago* (2.4 %), Liguliflorae (2.2 %), Cerealia type (2.1 %), Apiaceae (1.9 %), Brassicaceae (1.7 %).
				LB:	Increase of Chenopodiaceae, Tubuliflorae, Liguliflorae, *Rumex*, *Plantago*; Decrease of *Artemisia*, *Juniperus* type.
II	II2	96.0–114.6	14.5–29.3	AP:	*Quercus ithaburensis* type (15.2 %), *Juniperus* type (4.8 %), *Quercus calliprinos* type (1.1 %).
				NAP:	*Artemisia* (26.5 %), Chenopodiaceae (26.4 %), Poaceae (12 %), Apiaceae (2.9 %), Cerealia type (2.5 %), Tubuliflorae (1.7 %).
				LB:	Increase of Chenopodiaceae, Poaceae; Decrease of *Quercus ithaburensis* type.
II	II3	114.6–168.1	29.3–64.8	AP:	*Quercus ithaburensis* type (23.6 %), *Juniperus* type (2.9 %), *Quercus calliprinos* type (1.1 %).
				NAP:	Chenopodiaceae (24.1 %), *Artemisia* (23.9 %), Poaceae (10.4 %), Cerealia type (2.1 %), Apiaceae (1.6 %), Tubuliflorae (1.6 %).
				LB:	Increase of *Quercus ithaburensis* type, *Artemisia*; Decrease of Chenopodiaceae, *Plantago*, Liguliflorae.
II	II4	168.1–199.1	64.8–87.6	AP:	*Quercus ithaburensis* type (18.7 %), *Juniperus* type (1.6 %), *Pistacia* (1.6 %).
				NAP:	Chenopodiaceae (31 %), *Artemisia* (14.1 %), Poaceae (13.7 %), Tubuliflorae (2.6 %), *Plantago* (2.4 %), Cerealia type (2 %), Liguliflorae (1.9 %), Brassicaceae (1.6 %), Apiaceae (1.4 %), *Rumex* (1.4 %).
				LB:	Not defined (end of record).

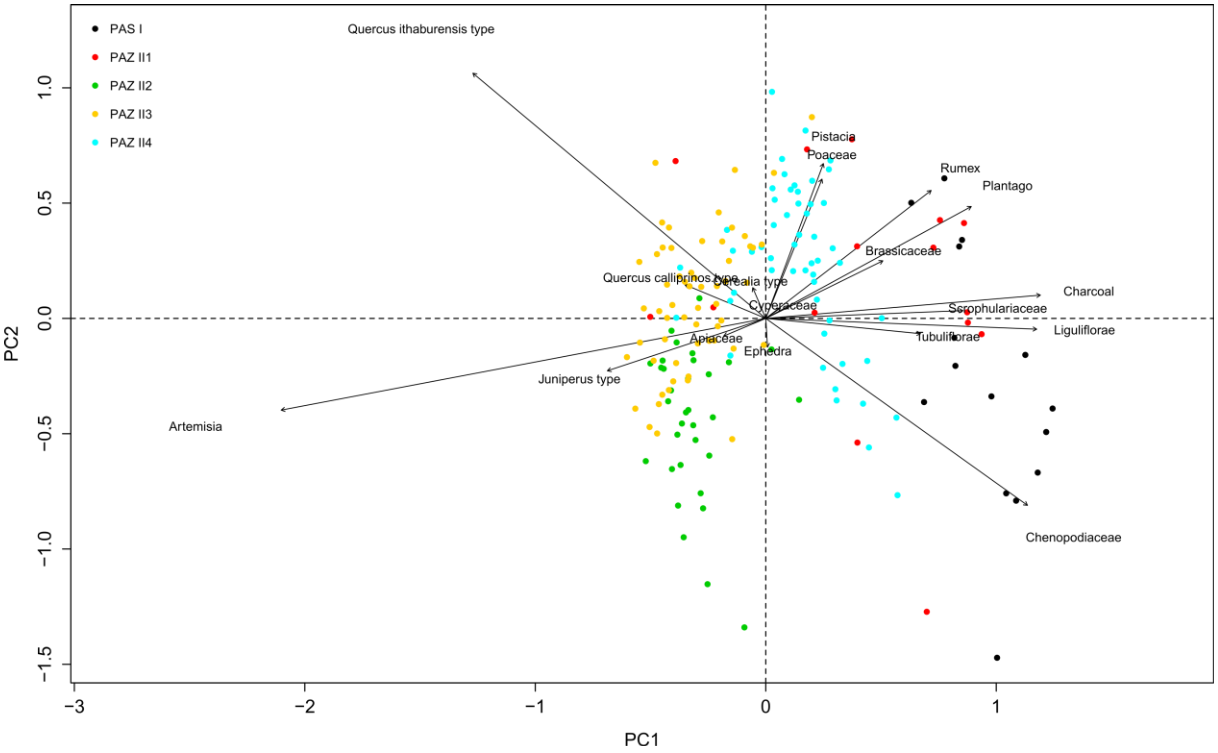


Figure 4.3: Biplot of the principal component analysis (PCA) including most abundant pollen taxa and charcoal (based on the total pollen sum). A square root transformation scaling was applied. PC1 and PC2 explain 54.9 % and 14.1 % of the total variance, respectively.

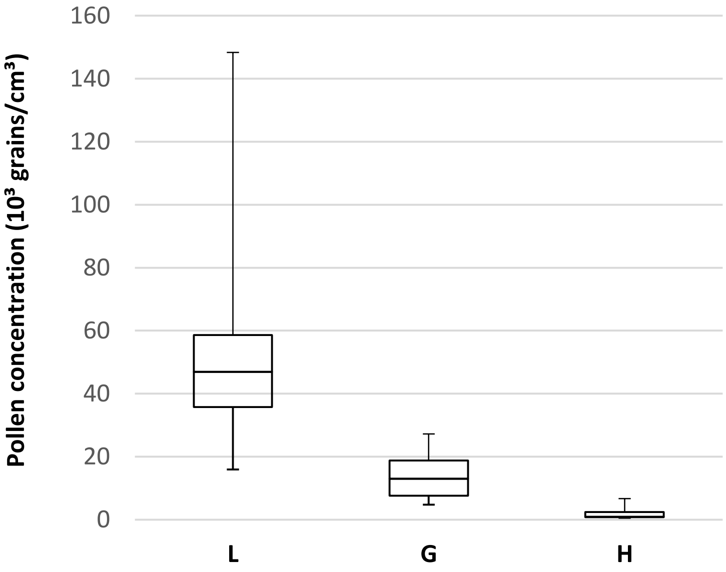


Figure 4.4: Boxplots of pollen concentrations in different sediment types (L: laminae without gypsum, G: massive gypsum and laminae with much gypsum, H: halite). Minimum and maximum values (whiskers), lower and upper quartile (box), and median (horizontal line) are shown.

The sampled sediments for this palynological investigation are comprised of three types: (a) laminae that are mainly comprised of alternating aragonite and detritus without gypsum, (b) massive gypsum deposits or laminae containing much gypsum (gypsum was not dissolved in the applied pollen preparation and was therefore easily identified in the pollen slides), and (c) halite (cf. Neugebauer et al., 2014). Pollen concentrations vary considerably between these sediment types (Fig. 4.4). Highest pollen concentrations are found in laminae without gypsum, lowest values correlate with halite samples. Previous studies showed the potential of pollen concentration as a proxy for vegetation density and pollen productivity supporting interpretations of pollen percentages (e.g., Miebach et al., 2016). However, here it appears that changes in vegetation density and pollen productivity are overprinted by rapid changes in sedimentation rates. Gypsum and halite have higher sedimentation rates than alternating aragonite-detritus laminae (Stein, 2001; Torfstein et al., 2015). This conclusion is supported by simultaneously dropping concentrations of charcoal and fungi in gypsum and halite samples (Fig. 4.7). Therefore, the pollen concentration of the Dead Sea core 5017-1 is no confident proxy for plant cover and vegetation productivity.

4.5.2 Vegetation history

The vegetation in the Dead Sea region was generally dominated by open vegetation during the Last Glacial and early Holocene (ca. 88–9 ka BP; Fig. 4.5). Large pollen amounts of Chenopodiaceae (goosefoot family), *Artemisia* (wormwood), and Poaceae (grasses) indicate the widespread occurrence of herb and dwarf shrub communities. These wind-pollinated plants, which are very abundant in the pollen assemblage, were accompanied by insect-pollinated plants, which are usually not represented or underrepresented in pollen diagrams (Faegri and Iversen, 1989). Although most taxa can occur in various biomes, some taxa are particularly common in single biomes and therefore represent such vegetation types. Chenopodiaceae are main representatives of the Saharo-Arabian desert biome, which nowadays receives very low annual precipitations of 100 mm and less (Zohary, 1962; Litt et al., 2012). The plant family contains many drought-adapted and salinity-tolerant species (Rossignol-Strick, 1995; van Zeist et al., 2009). *Artemisia* is the dominating plant of today’s Irano-Turanian steppe biome (Zohary, 1962) and tolerates aridity though less extreme than Chenopodiaceae (Rossignol-Strick, 1995). *Artemisia* is adapted to somewhat higher precipitation rates of ca. 100–350 mm (Zohary, 1962). Modern studies showed that *Artemisia* pollen increase and Chenopodiaceae pollen decrease with decreasing aridity. Therefore, A/C (*Artemisia*/Chenopodiaceae) ratios can be used as a moisture indicator, particularly in primary non-forested areas (El-Moslimany, 1990). Poaceae are also associated with the Irano-Turanian steppe biome (Litt et al., 2012), although its various species admix into a range of vegetation types (Danin, 1992, 1999). Poaceae comprise of a wild pollen type and a Cerealia pollen type, which can morphologically be distinguished. While the wild type refer to the majority of wild grasses, the Cerealia type contain domesticated cereals, their ancestors, but also some wild grass species (Beug, 2004).

Trees and shrubs never dominated the Dead Sea region during the investigated period. Nevertheless, they contributed substantially to the pollen composition (averagely 24.6 %). *Quercus ithaburensis* type (deciduous oaks) was the most abundant arboreal pollen type, followed by *Juniperus* type (juniper and Mediterranean cypress), *Quercus calliprinos* type (evergreen oaks), and *Pistacia* (pistachio). While deciduous and evergreen oaks are usually well represented (van Zeist et al., 1975), *Pistacia* and *Juniperus* type are usually underrepresented in the pollen precipitation (Rossignol-Strick, 1995; van Zeist et al., 2009). All of these trees and shrubs represent the Mediterranean biome (Baruch, 1986; Litt et al., 2012), which occurs nowadays in the most humid areas of the southern Levant (Zohary, 1962). Modern Levantine vegetation studies indicated that a reduction of arboreal vegetation coincides with a decline in moisture (Kadmon and Danin, 1999). The amount of arboreal pollen is therefore probably strongly related to changes in available moisture for plants in the past, i.e. effective moisture, which depends mainly on precipitation and evaporation rates. Temperature was most likely a minor factor limiting biome distribution in the subtropical southern Levant, although temperature variations would have changed the species composition within biomes. Still, other factors such as seasonality, local habitats, and insolation must be considered for evaluating vegetation changes in the past.

PAZ II4 (199.1–168.1 m; 87.6–64.8 ka BP) corresponds to MIS 5b/a and the early MIS 4. An open vegetation with a variety of herbs and dwarf-shrubs prevailed (Fig. 4.5). Chenopodiaceae accompanied by *Artemisia* and Poaceae were important elements of the vegetation. Various herbaceous taxa further contributed to the composition of the vegetation, namely Tubuliflorae, Liguliflorae (both composites), *Plantago* (plantain), *Rumex* (dock), Brassicaceae (crucifers), and Apiaceae (umbellifers). Moderate pollen amounts of *Quercus ithaburensis* type and small pollen amounts of *Pistacia*, *Juniperus* type, and *Quercus calliprinos* type indicate the occurrence of Mediterranean woodland elements. Trees and shrubs did probably not occur in a closed forest belt but were patchily distributed in habitats with locally more effective moisture. They most likely formed a mosaic with Irano-Turanian steppe components (steppe-forest).

Several fluctuations in the vegetation indicate millennial-scale climate events with at least three phases of reduced available moisture expressed by Chenopodiaceae peaks (Fig. 4.5). Neugebauer et al. (2016) correlated dry phases during the early Last Glacial derived from micro-facies analyses from the Dead Sea core 5017-1 to cold phases in the North Atlantic coinciding with stadial conditions (mostly cold and dry) in other Mediterranean records. Following this interpretation, the detected dry phases might correlate to Greenland stadials (cf. NGRIP members, 2004). However, the current chronology does not allow a convincing correlation to single climate events of other paleorecords. Thus, the connection between rapid vegetation changes in the Dead Sea region and high latitude climatic conditions during this phase remains speculative.

PAZ II3 (168.1–114.6 m; 64.8–29.3 ka BP) corresponds to the late MIS 4 and MIS 3. At the onset of PAZ II3, a change in the pollen composition of herbaceous plants occurs (Fig. 4.5). *Artemisia* pollen percentages increase while the pollen frequencies of a range of taxa, namely Chenopodiaceae, Poaceae, Tubuliflorae, Liguliflorae, *Plantago*, *Rumex*, and Brassicaceae, decline. The change in non-arboreal pollen is also indicated by increased A/C values (Fig. 4.9). Moreover, the onset of PAZ II3 displays an increase of arboreal pollen. Overall highest mean percentages of *Quercus ithaburensis* type occur in PAZ II3. The pollen composition mirrors a spread of Mediterranean woodland components and *Artemisia* steppe implying an increase of available moisture for plants. In Greenland, the end of MIS 4 and MIS 3 were characterized by frequent and rapid fluctuations between stadial and interstadial conditions. Compared to previous and later phases, durations of stadials were shorter, and averagely

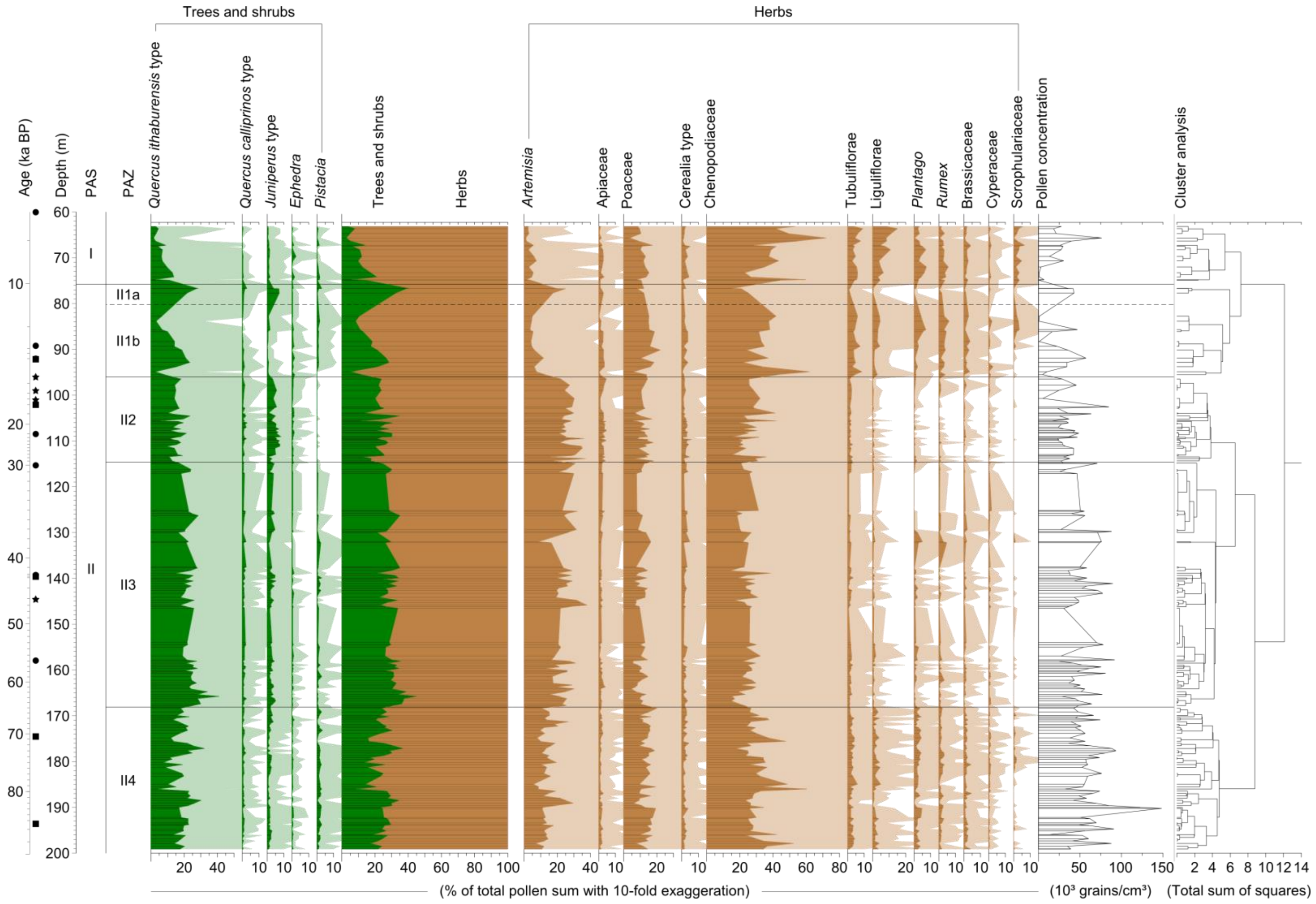


Figure 4.5: Pollen diagram of the Dead Sea core 5017-1 with most abundant taxa, pollen concentrations, cluster analysis, PASs (pollen assemblage superzones), and PAZs (pollen assemblage zones). The chronology is based on a linear interpolation of calibrated radiocarbon dates (circles), Uranium-Thorium dates (squares), and correlated Uranium-Thorium dates (stars; see Table 4.1).

warmer climatic conditions prevailed (NGRIP members, 2004). Therefore, increased effective moisture in the Dead Sea region during the late MIS 4 and MIS 3 would coincide with previously described relationships between warm northern high latitude conditions and moist conditions in the southern Levant (and vice versa) during the Last Glacial (Bartov et al., 2003; Torfstein et al., 2013b; Neugebauer et al., 2016). However, this connection was suggested for short-term hydroclimatic fluctuations. On longer scales, most authors agreed on a contrasting pattern, namely the coincidence of warmer phases (e.g., Holocene, MIS 3) at the North Atlantic with drier phases in the southern Levant (e.g., Enzel et al., 2008; Stein et al., 2010; Neugebauer et al., 2016). The palynological result contradicts a previous vegetation model (Horowitz, 1992) that suggested the reduction of woodland components in the Dead Sea region during MIS 3.

PAZ II2 (114.6–96.0 m; 29.3–14.5 ka BP) corresponds to MIS 2. The vegetation composition and abundance of single taxa of PAZ II2 largely resemble those of PAZ II3 as supported by the cluster analysis (Fig. 4.5) and PCA (Fig. 4.3), which indicate that PAZ II3 and PAZ II2 are the most similar pollen zones. However, an important ecological difference appears within arboreal components. While thermophilous deciduous oaks became less abundant, *Juniperus* and/or *Cupressus sempervirens* (*Juniperus* type) spread. A virtual absence of frost-sensitive *Pistacia* point to reduced winter temperatures in areas where *Pistacia* previously had grown (Rossignol-Strick, 1995). The palynological results suggest a similar availability of moisture for plants during MIS 2 relative to MIS 3. Considering lower temperatures and a reduced evaporation, even reduced precipitation rates during MIS 2 would be possible resulting in a similar amount of effective moisture compared to MIS 3 (cf. Stockhecke et al., 2016).

Previous studies correlated a prominent gypsum layer termed “Upper Gypsum Unit” (UGU) from stratigraphic sections of the Lisan Formation along the Dead Sea Basin and a sharp lake level drop of Lake Lisan with Heinrich event 1 (Bartov et al., 2003; Stein et al., 2010; Torfstein et al., 2013a, b). Heinrich events are associated with the deposition of ice-rafted debris in the North Atlantic caused by massive discharges of icebergs (Heinrich, 1988; Bond et al., 1992). They are linked to dramatic climate shifts in the northern hemisphere (Hemming, 2004). Bartov et al. (2003) postulated that the addition of freshwater to the North Atlantic resulted in a decline of Mediterranean sea-surface temperatures (SSTs). The decline of SSTs caused a reduction in the frequency and intensity of storms that delivered moisture to the southern Levant. As a result, lake levels of Lake Lisan abruptly dropped but recovered soon and fast again. The UGU was later correlated to core 5017-1 at a depth of ca. 101–99 m (Neugebauer et al., 2014). The pollen concentration shows a sharp decline corresponding to the UGU (Fig. 4.5, 4.7; see also section 4.5.1). However, no significant changes in pollen percentages are visible. Therefore, the pollen analysis do not support a pronounced drier phase. Additional pollen samples will be analyzed to confirm this result.

PAZ II1 (96.0–75.8 m; 14.5–10.0 ka BP) corresponds to the Lateglacial and Pleistocene-Holocene transition. The onset of PAZ II1 marks the strongest shift in the vegetation during the investigated time as indicated by the cluster analysis (Fig. 4.5). Moreover, pollen spectra show the strongest variability of all pollen zones as underlined by the PCA (Fig. 4.3), which do not group samples of PAZ II1 together. PAZII1 was grouped into two subzones (a and b).

PAZ II1b can be further subdivided into two phases. The first phase is marked by a pronounced peak of Chenopodiaceae and a simultaneous drop of all other taxa shown in Fig. 4.5 except for Tubuliflorae and Liguliflorae. The second phase displays a gradual decrease of trees and shrubs in favor of Chenopodiaceae and other non-arboreal plants. Both phases have in common: a) remarkably low percentages of *Artemisia* compared to earlier phases and b) the variety of herbs resembling the composition of PAZ II4. Therefore, it is probable that the initial peak of Chenopodiaceae reflects a local spread of Chenopodiaceae engendering a temporal overrepresentation in the pollen assemblage and a statistical suppression of other taxa. A local spread of pioneer plants is supported by a simultaneous major lake level drop of Lake Lisan from ca. 260 to 465 m bmsl, one of the lowest stands during the Late Quaternary (Stein et al., 2010). The exposed shores could have been vegetated by saline-tolerant pioneer communities including species of Chenopodiaceae and Asteraceae (cf. Aloni et al., 1997). Due to the wind-pollination of Chenopodiaceae, local stands of this family are particularly overrepresented in the pollen diagram. A similar peak of Chenopodiaceae was observed after a strong lake level decline at the Sea of Galilee at ca. 24–23 ka BP (Miebach et al., submitted). Frost-sensitive *Pistacia* occurs consistently again after a virtual absence of many millennia. This indicates a return to higher temperatures at least during winters (Rossignol-Strick, 1995). The reduction of *Juniperus* type, which was common during the cold MIS 2 including the Last Glacial Maximum, also implies higher temperatures. The strong decrease of *Artemisia* steppe indicate less effective moisture in open habitats relative to previous phases. A negative water balance during this phase is supported by the deposition of gypsum and halite in core 5017-1 (Neugebauer et al., 2014; Fig. 4.9) indicating dry sedimentary facies (Torfstein et al., 2015; Fig. 4.9) and by the major lake level drop of Lake Lisan (Stein et al., 2010). However, the delayed decrease of *Quercus ithaburensis* type suggest that moister conditions prevailed somewhat longer in local habitats where deciduous oak had grown.

PAZ II1a is characterized by a spread of forest-steppe (increase of *Artemisia*, *Quercus ithaburensis* type, and *Juniperus* type) going along with the reduction of Chenopodiaceae, Tubuliflorae, Liguliflorae, *Plantago*, *Rumex*, and Scrophulariaceae. The pollen assemblage indicates an increase of available moisture for plants.

The detailed chronology of vegetation changes corresponding to PAZ II1 remains up to now hypothetic given the number of available ^{14}C and U-Th dates of core 5017-1. Only the onset of PAZ II1 is well dated with a ^{14}C date, a U-Th date, and a correlated U-Th date (Table 4.1) indicating that the onset of PAZ II1 coincides with the onset of the Lateglacial Interstadial (LGI, synonym of Bølling-Allerød and Dansgaard-Oeschger event 1). The interstadial was firstly described in Central European pollen studies (Litt, 2007 and references therein). It was also identified in many Eastern Mediterranean pollen records (e.g., Litt et al., 2009; Shumilovskikh et al., 2012; Panagiotopoulos et al., 2013) and in Greenland ice core records, where it was dated to ca. 14.6–12.9 ka BP (Rasmussen et al., 2014). PAS I was radiocarbon dated to the early Holocene (Neugebauer et al., 2014; Hiroyuki Kitagawa, pers. comm.) suggesting that PAZ II1 encompasses the time between the onset of the LGI and the early Holocene. Although an additional calibrated ^{14}C date of 11.4±0.1 ka BP (Neugebauer et al., 2014) exists in PAZ II1, I discuss three hypotheses about possible chronologies (Fig. 4.6a): a radiometric timescale (hypothesis 1) and biostratigraphic timescales (hypothesis 2 and 3).

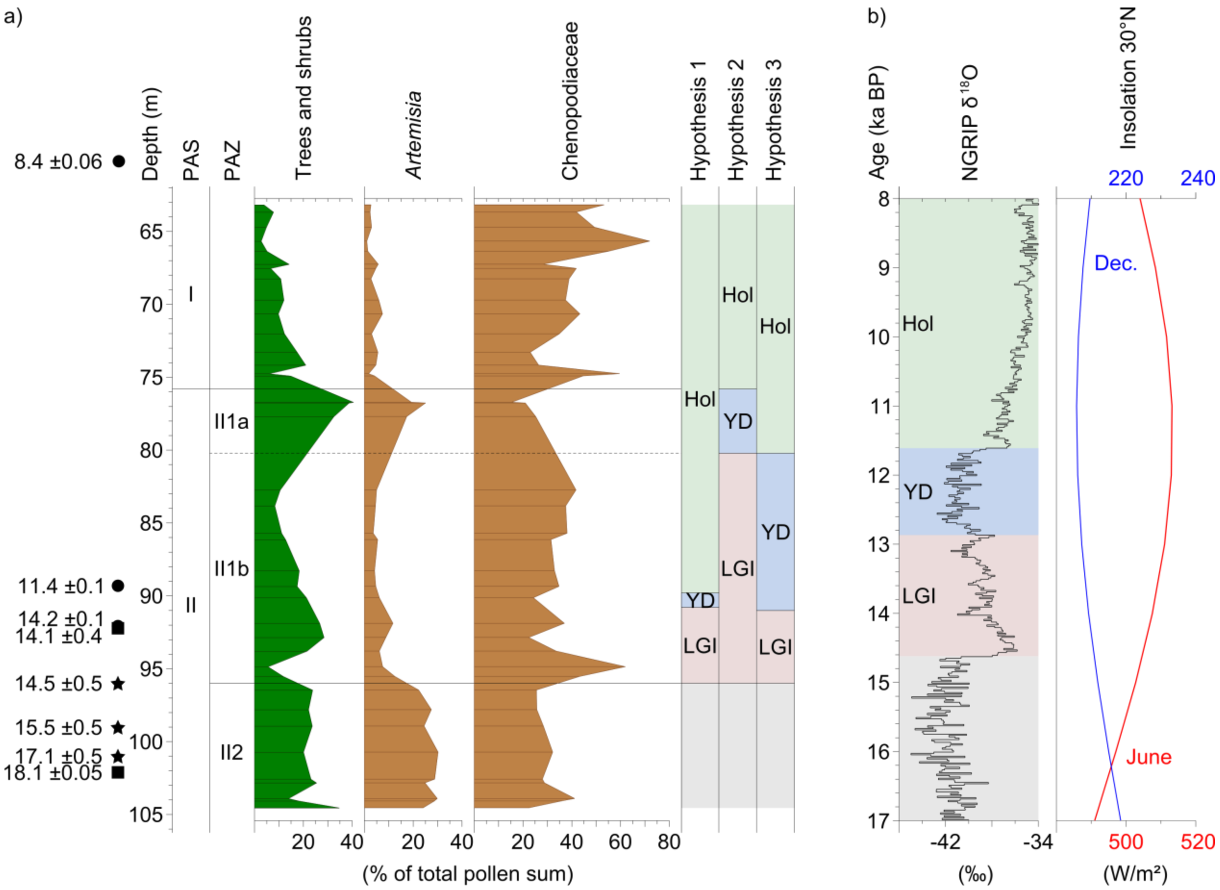


Figure 4.6: a) Selected Lateglacial and early Holocene pollen curves from the Dead Sea core 5017-1 with three chronological hypotheses discussed in the text. Calibrated radiocarbon dates (circles), Uranium-Thorium dates (squares), and correlated Uranium-Thorium dates (stars; see Table 4.1) are given. PAS: pollen assemblage superzone. PAZ: pollen assemblage zone. Hol: Holocene. YD: Younger Dryas. LGI: Lateglacial Interstadial. b) Greenland $\delta^{18}O$ record (Rasmussen et al., 2014; Seierstad et al., 2014) and June and December insolation for the 30th parallel north (Berger and Loutre, 1991).

Hypothesis 1: If the ^{14}C date of 11.4±0.1 ka BP will be confirmed, sediments that were deposited during the late LGI and Younger Dryas (YD) would be very condensed, i.e. there would have been very low sedimentation rates. The vegetation during the LGI and YD would have been very similar, and several major vegetation changes would have occurred during the earliest phase of the Holocene. Assuming a hydroclimatic connection between the Dead Sea region and the North Atlantic (cf. Bartov et al., 2003; Torfstein et al., 2013b), this scenario is unlikely. While the Lateglacial was characterized by strong changes between warm phases (LGI) and cold phases (YD) at northern high latitudes, the early Holocene was a stable warm stage (Rasmussen et al., 2014; Seierstad et al., 2014; Fig. 4.6b). Thus, another vegetation pattern can be expected for the Dead Sea region. A higher resolution of the pollen analysis could reveal further shifts in the vegetation during the YD though.

From a biostratigraphic point of view based on changes in the pollen composition, two other chronological frameworks are more likely. Hypothesis 2 and 3 assume that the radiocarbon date of 11.4±0.1 ka BP will not be confirmed and suggest a pollen signal based revision of the current chronology.

Hypothesis 2: The whole PAZ II1b would be associated with the LGI suggesting an early LGI with moderately low available moisture in open habitats and a persistence of moister conditions in local habitats where deciduous oaks had grown (Fig. 4.6a). The late LGI would have seen a further reduction of *Artemisia* steppe and a strong decline of Mediterranean woodland components implying much reduced available moisture for plants. This scenario would largely coincide with observations by Stein et al. (2010), who suggested that the LGI was one of the driest phases at the Dead Sea. A negative water balance during the LGI would apparently contradict previous palynological studies. An increase of arboreal pollen in the marine core 9509 from the southeastern Levantine Basin (Langgut et al., 2011) and in the terrestrial core from Yammouneh Valley, Lebanon, (Gasse et al., 2011, 2015) suggest humid conditions during the LGI. Although increased precipitation rates could have engendered the spread of forests in other parts of the Levant, higher temperatures (cf. Ayalon et al., 2013; Rasmussen et al., 2014; Seierstad et al., 2014; Fig. 4.6b) and a higher summer insolation (cf. Berger and Loutre, 1991; Fig. 4.6b) could have caused a steadily decreasing precipitation/evaporation ratio, i.e. a negative water balance, in the Dead Sea region during the LGI. The YD would be associated with PAZ II1a suggesting more available moisture for plants during the YD (spread of forest-steppe). Wet conditions in the Dead Sea region were already proposed by Stein et al. (2010) based on lithostratigraphic considerations of Lake Lisan/Dead Sea sediments and lake level reconstructions. Also Liu et al. (2013) concluded wet climatic conditions during the YD inferred from rock varnish from recessional shorelines of Lake Lisan/Dead Sea.

Hypothesis 3: The lower PAZ II1b would be associated with the LGI implying a persistence of moister conditions in local habitats where deciduous oak had grown and less effective moisture in open habitats causing a reduction of *Artemisia* steppe (Fig. 4.6a). As discussed before, the reduction of effective moisture would not exclude higher precipitation rates in the Dead Sea region allowing a similar precipitation mechanism in the whole Eastern Mediterranean. During the YD (upper PAZ II1b), moisture deficits would have amplified resulting in a further reduction of *Artemisia* steppe and a reduction of deciduous oak stands. Dry climatic conditions during the YD were suggested by many Eastern Mediterranean pollen studies (e.g., Bottema, 1995; Kotthoff et al., 2008; Litt et al., 2009). Consequently, dry phases expressed by Chenopodiaceae increases in several Levantine pollen records were also ascribed to the YD (e.g., Rossignol-Strick, 1995; Meadows, 2005; Cheddadi and Khater, 2016). However, independent chronologies confirming this scenario were lacking. Also Orland et al. (2012) carefully suggested more arid conditions for central Israel during the YD relative to the Holocene derived from speleothem data of the Soreq Cave. PAZ II1a would be associated with the early Holocene. The renewed spread of Mediterranean woodland components and *Artemisia* steppe implies that more moisture would have been available for plants during the early Holocene. A spread of forests at the onset of the Holocene was already suggested by other palynological investigations from the Eastern Mediterranean (e.g., Rossignol-Strick, 1995; Müller et al., 2011; Miebach et al., 2016). Hence, dry conditions in the Dead Sea region during the YD followed by more humid conditions during the early Holocene would coincide with other parts of the Eastern Mediterranean. Hypothesis 3 is very probable given the coincidence with other Eastern Mediterranean vegetation studies and the increase of Mediterranean woodland components at the onset of the Holocene. At least in the northern part of the Dead Sea catchment a woodland expansion at the onset of the Holocene can be expected.

PAS I (75.8–63.2 m; 10.0–8.7 ka BP) corresponds to the early Holocene. The onset of PAS I either corresponds to the onset of the Holocene (following hypothesis 2) or a slightly later time (following hypothesis 1 and 3) but no later than 9.7 ka BP (Hiroyuki Kitagawa, pers. comm.). Herbs and dwarf shrubs dominated the landscape, while trees and shrubs but also *Artemisia* were minor constituents of the vegetation (Fig. 4.5). Chenopodiaceae were important elements of the vegetation and were accompanied by other herbaceous taxa similar to PAZ II4 and PAZ II1. But particularly amounts of Liguliflorae, Tubuliflorae, *Plantago*, and Scrophulariaceae were higher than before. The pollen composition and relative abundance of singe taxa are in good agreement with the pollen diagram from Ein Gedi, western Dead Sea shore, which encompasses the past 10 ka BP (Litt et al., 2012).

The significant reduction of woodland components and *Artemisia* steppe was either caused by a climatic change resulting in few available moisture for plants, an anthropogenic change of the environment, or a combination of both. The abrupt vegetation change at the onset of PAS I coincides with a simultaneous deposition of halite in core 5017-1 (Neugebauer et al., 2014; Fig. 4.9) suggesting a negative water balance and thus supporting a climatic cause of the vegetation change. During the early Holocene (11.7–10.5 ka BP), Pre-Pottery Neolithic A (PPNA) communities settled in the southern Levant, particularly in the Jordan Valley at local water resources. In contrast, presently hyperarid areas on the Jordanian plateau and in the Negev desert that were intensively exploited by Epipaleolithic people prior to the PPNA were virtually abandoned during the PPNA (Kuijt and Goring-Morris, 2002). On the one hand, the archaeological record supports drier conditions and thus a climatic cause for the vegetation change. On the other hand, it indicates the increasing anthropogenic influences in the Dead Sea region. The anthropogenic influences amplified during the Pre-Pottery Neolithic B/C (PPNB/C: 10.5–8.25 ka BP) when the regional population grew and aggregated in larger settlements (Kuijt and Goring-Morris, 2002). Archaeological remains of PPNB/C provide clear evidence for plant cultivation and animal domestication (Shea, 2013). Rollefson and Köhler-Rollefson (1992) emphasized the dramatic impact of Neolithic settlers on southern Levantine woodlands. A high tree consumption for plaster production and house construction together with a widespread goat pastoralism resulted in a cumulative loss of tree cover, changed plant communities, and increased erosion rates.

4.5.3 Vegetation gradient during MIS 2

Today, precipitations, temperatures, and the vegetation distribution follow strong gradients in the southern Levant. Mediterranean forests occur in a vegetation belt in the north reaching into the Judean Mountains and the hilltops of the rift valley east to the Dead Sea (Zohary, 1962; Fig. 4.2). A similar pattern could have prevailed during the Last Glacial. Alternatively, Mediterranean forests were patchily distributed in locally advantaged habitats. The comparison of the Dead Sea pollen record from core 5017-1 and a pollen record from the Sea of Galilee (Lake Kinneret), northern Israel (core KIN2; Miebach et al., submitted) helps to reveal the woodland pattern during MIS 2. The well-dated and high-resolution pollen record from the Sea of Galilee provides information for MIS 2 when Lake Lisan and the Sea of Galilee reached high stands, which ultimately caused the mergence of both lakes (Bartov et al., 2003; Hazan et al., 2005; Torfstein et al., 2013b). The regional vegetation is best mirrored in core KIN2 during ca. 28–24 ka BP because local vegetation and unsuitable preservation conditions probably affected the pollen composition before and after this period. In contrast to the middle and late Holocene (cf. Schiebel, 2013), Mediterranean forests were considerably reduced in the vicinity of the Sea of Galilee during ca. 28–24 ka BP. Percentages of the main arboreal component, namely *Quercus ithaburensis* type, are similar to the Dead Sea pollen record. However, *Juniperus* and/or *Cupressus sempervirens* played a greater role in the Dead Sea region resulting in somewhat higher arboreal pollen sums. The composition of non-arboreal pollen broadly coincides in both records, although abundances partly differ. Increased Cyperaceae and Poaceae percentages at the Sea of Galilee indicate a higher component of local vegetation in the pollen assemblage. Higher Chenopodiaceae values in the Dead Sea pollen record mirror the closer proximity to arid and hyperarid regions. The comparison suggests that dwarf shrubs, grasses, and other herbs predominated in the whole study area. There was no continuous and dense Mediterranean woodland belt in the vicinity of the Sea of Galilee. Thermophilous trees were rather patchily distributed in the whole study area. The gradient of available water for plants between the Sea of Galilee and the Dead Sea/Lake Lisan was not as strong as today.

4.5.4 Fire history

The analysis of charred particles in sediments is one of the primary methods to reconstruct fire activity in the past. Charcoal particles above 100 µm in size are not transported far from fire sources. Thus, they indicate local fires. Smaller charcoal particles are able to travel longer distances and therefore reflect regional fires (Whitlock and Larsen, 2001). Several previous studies showed the suitability of microscopic charcoal to reconstruct fire events and long-term fire regimes in the past. The comparison with pollen assemblages allowed insights into the relationship between fire, vegetation, and climate (e.g., Swain, 1973; Daniau et al., 2010; Vannière et al., 2011).

Hereafter, I discuss the results of the microscopic charcoal analysis of the investigated Lake Lisan/Dead Sea sediments. I address 1) the relationship between microscopic charcoal and pollen, 2) relative changes in biomass burning over time, and 3) possible factors that influenced the charcoal record.

Charcoal concentrations in the investigated sediments vary from 0 to 7433 particles/cm^3 (meanly 1622 particles/cm^3). Changes in charcoal concentrations coincide with pollen concentration variations, particularly in the upper part of the stratigraphic column (Fig. 4.7). Since pollen concentration is a proxy for vegetation density, the coincidence could suggest that charcoal production is connected to the vegetation density, i.e. terrestrial biomass availability. However, the largely simultaneous changes with other concentrations such as fungi concentrations indicate that all concentrations are overprinted by alterations in the sedimentation rate. Those alterations are mainly caused by the occurrence of different sediment types with divergent sedimentation rates (Fig. 4.7, see also section 4.5.1). An influx calculation could solve this problem. However, precise sedimentation rates for the investigated sediments are currently not available and thus the calculation of reliable influx rates is not possible. Therefore, the ratio of charcoal to pollen (C/P) is more informative. There is a weak negative linear correlation between the C/P ratio and arboreal pollen and no significant linear correlation between the C/P ratio and Poaceae (Fig. 4.8). The PCA biplot (Fig. 4.3) places the microscopic charcoal together with the herbaceous taxa Scrophulariaceae, Liguliflorae, and Tubuliflorae. These relationships suggest that the fire frequency was not connected to forest density, grassland occurrence, and available fuel.

The C/P ratio in Fig. 4.7 indicates relative changes in biomass burning during the investigated period. It suggests a decrease in fire activity at ca. 65 ka BP, which coincides with the onset of PAZ II3. The fire activity stayed constantly low until ca. 17 ka BP. During the Lateglacial and early Holocene, the fire activity generally rose, but frequent changes in the C/P ratio indicate an unstable fire regime. While the timing of the first pronounced peak in C/P is still uncertain (see section 4.5.2), the other most pronounced peaks occur during the early Holocene.

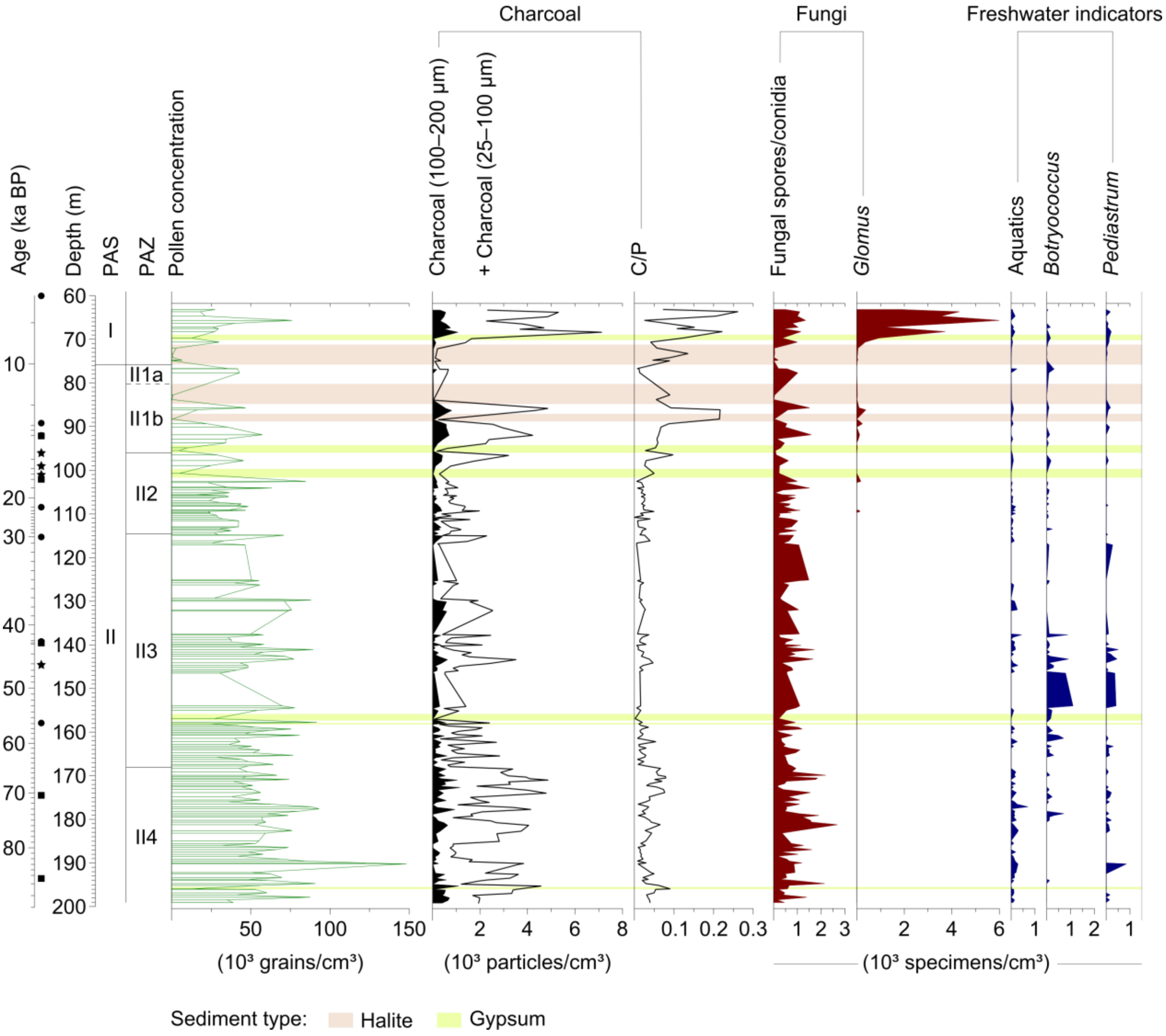


Figure 4.7: Correlation of selected pollen, non-pollen palynomorphs, and microscopic charcoal of the Dead Sea core 5017-1. Halite and gypsum sediment types of investigated pollen samples are marked. PAS: pollen assemblage superzone. PAZ: pollen assemblage zone. C/P: ratio of charcoal (both size fractions) to pollen. Fungal spores/conidia exclude *Glomus*. The chronology is based on a linear interpolation of calibrated radiocarbon dates (circles), Uranium-Thorium dates (squares), and correlated Uranium-Thorium dates (stars; see Table 4.1).

Different fire regimes are generally generated by atmospheric conditions, ignition agents, and the availability of consumable resources, i.e. vegetation (Moritz et al., 2010). According to Whitlock et al. (2010), highest fire activity is usually related to grassland and savanna biomes. Daniau et al. (2010)

reviewed changes in fire regimes during the Last Glacial on global scale and concluded that they were primary related to changes in plant productivity. Also previous studies from the Mediterranean and Near East that investigated the fire history during the Last Glacial and Holocene connected an enhanced fire activity to higher arboreal pollen percentages and an increased terrestrial biomass caused by higher temperatures and increased moisture (e.g., Daniau et al., 2007; Pickarski et al., 2015). In addition, an investigation from Hula Basin, northern Israel, found a connection between arboreal pollen as a biomass indicator and fire activity during the Holocene (Turner et al., 2010). In contrast, the results from the Dead Sea suggest that grassland occurrence, forest density, and thus vegetation productivity was not the primary trigger for changes in fire activity. Hence, climate variations or anthropogenic impacts are possible factors that primary influenced the Dead Sea charcoal record, particularly since the Lateglacial. Such climate variations could be for instance a global temperature increase (cf. Daniau et al., 2010) or longer/more intensive summer droughts (cf. Vannière et al., 2011). In fact, Orland et al. (2012) suggested a decreased seasonal rainfall gradient prior to 15 ka BP inferred from Soreq Cave speleothems. After 15 ka BP and particularly during the Holocene, the climatic conditions were characterized by higher seasonality with distinct wet and dry seasons. Alternatively, human activities in the catchment of the Dead Sea could be the major factor for the increased fire activity since the Lateglacial. Anthropogenic impacts could be for instance changes in ignition rates or alternations in land cover (Whitlock et al., 2010). During the Lateglacial and Holocene, the southern Levantine environment was more and more influenced by human activities due to a rising population and changes in land use, e.g. agriculture and pastoralism (Miller, 1991; Kuijt and Goring-Morris, 2002). These structural, social, and environmental changes were probably accompanied by a change in fire activity.

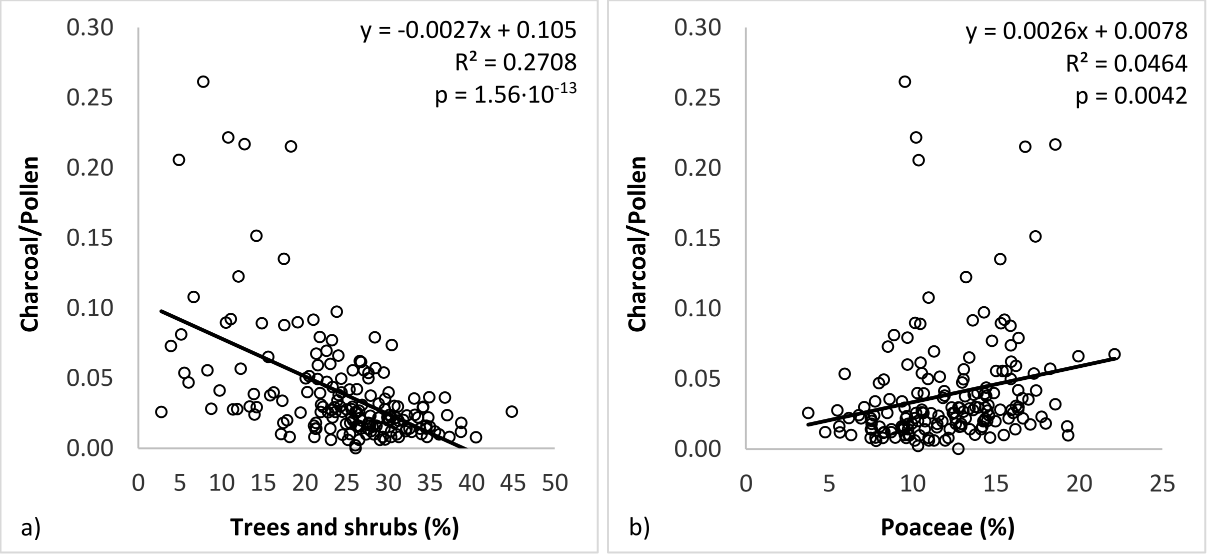


Figure 4.8: Relationship between the ratio of charcoal to pollen and a) trees and shrubs and b) Poaceae. Regression line, coefficient of determination (R^2), and probability value (p-value) are given.

4.5.5 Freshwater and erosion indicators

The modern Dead Sea is a hypersaline water body with very few, well-adapted microorganisms (Oren, 1997). In contrast, during major parts of the Last Glacial, Lake Lisan was stratified into an upper freshwater layer and a lower brine layer (Stein, 2001; Lazar et al., 2014). Therefore, it allowed other biological communities to live in. The palynological results from the Dead Sea core 5017-1 indicate the frequent occurrence of freshwater indicators along the whole investigated stratigraphic column (Fig. 4.7). Here, freshwater indicators are colony-forming green algae *Botryococcus* and *Pediastrum* and pollen from aquatic plants. However, their indicative value for water conditions is limited. Firstly, the concentrations are very low. Rivers, particularly the Jordan River, could have transported such low numbers of green algae and pollen into Lake Lisan. Thus, it is not clear if the algae and aquatic plants grew in Lake Lisan. Secondly, there are few distinct changes of the concentrations in time, but there is rather a noisy background signal. Aquatics are somewhat more abundant from ca. 88 to 65 ka BP, which corresponds to PAZ II4. *Botryococcus* concentrations are higher though not constant between ca. 75 and 41 ka BP. There is no reduction of freshwater indicators since the LGI when the lake level of Lake Lisan abruptly and significantly dropped (Stein et al., 2010) breaking most likely the stable stratification (Lazar et al., 2014).

Fungal remains are constantly present in the investigated Lake Lisan/Dead Sea sediments and are more abundant than freshwater indicators (Fig. 4.7). Particularly informative are analyzed spores of the fungus *Glomus*. It is an arbuscular mycorrhizal fungus, which lives in symbiosis with a variety of host plants and sporulates under the ground. *Glomus* spores observed in lake sediments are indicative of soil erosion in the catchment area, which can be either natural or human-induced (Anderson et al., 1984; Marinova and Atanassova, 2006; Shumilovskikh et al., 2016). The conspicuous increase of *Glomus* spores in the investigated Lake Lisan/Dead Sea sediments during the early Holocene points therefore to an abrupt rise of soil erosion in the catchment. On the one hand, the increased soil erosion could be naturally induced, e.g. caused by a climate-induced reduction of woodland (see section 4.5.2) resulting in an unstable surface cover. On the other hand, enhanced erosion rates could be caused by anthropogenic activities in the catchment of the Dead Sea. During the early Holocene, southern Levantine settlements mainly clustered along the Jordan Valley (in particular during PPNA). The population size increased gradually and people heavily exploited the environment (Kuijt and Goring-Morris, 2002). The anthropogenic reduction of woodland and widespread herding of goats and other domesticated animals resulted in exposed soils and an increased erosion (Rollefson and Köhler-Rollefson, 1992). Thus, anthropogenic causes for the detected increase in erosion rates at the Dead Sea are very likely.

4.6 Conclusions and future perspectives

I analyzed the palynological assemblage of the Lisan Formation and upper Zeelim Formation of the Dead Sea core 5017-1 spanning ca. 88–9 ka BP. The pollen record indicates a dominance of Irano-Turanian steppe and Saharo-Arabian desert vegetation. However, Mediterranean woodland elements considerably contributed to the vegetation composition during most of the investigated period.

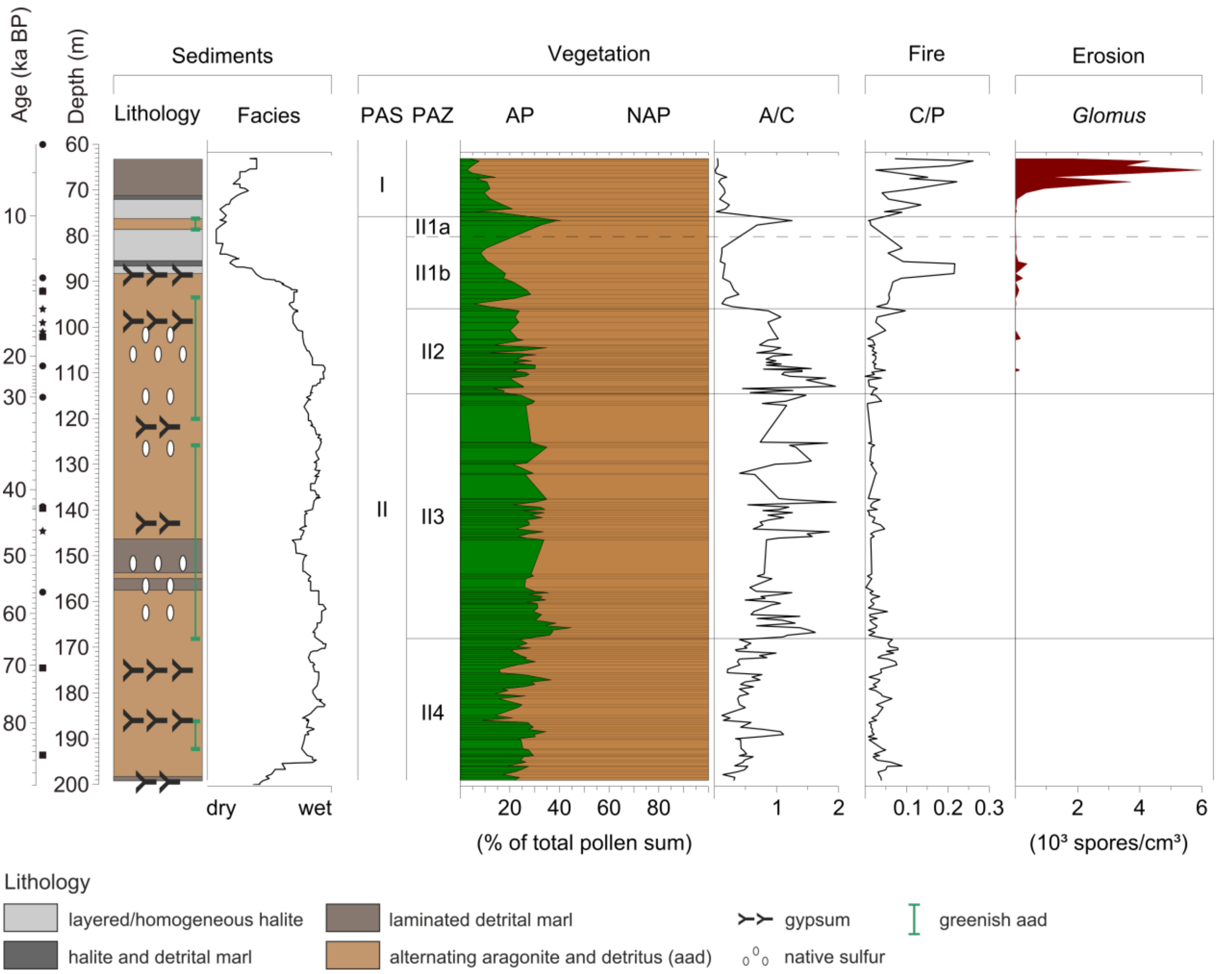


Figure 4.9: Summary diagram for sediments, vegetation, fire activity, and catchment erosion inferred from the Dead Sea core 5017-1. The lithology refers to Neugebauer et al. (2014), and the facies curve refers to Torfstein et al. (2015). PAS: pollen assemblage superzone. PAZ: pollen assemblage zone. AP: arboreal pollen. NAP: non-arboreal pollen. A/C: ratio of *Artemisia* to Chenopodiaceae. C/P: ratio of charcoal to pollen. The chronology is based on a linear interpolation of calibrated radiocarbon dates (circles), Uranium-Thorium dates (squares), and correlated Uranium-Thorium dates (stars; see Table 4.1).

Although changes in the pollen composition cannot provide clear evidence for variations in the precipitation amount, it indicates the availability of water for plants, i.e. the effective moisture. Increased ratios of trees/shrubs to herbs and *Artemisia* to Chenopodiaceae indicate high effective moisture. Thus, the pollen record suggests that effective moisture was consistently high during the late MIS 4, MIS 3, and MIS 2.

During MIS 2, the Dead Sea region suffered the lowest temperatures of the investigated period as indicated by changes in arboreal components. The comparison of pollen records from Dead Sea and Sea of Galilee indicate that, at least between 28–24 ka BP during MIS 2, the gradient of available water for plants between the Sea of Galilee and the Dead Sea/Lake Lisan was not as strong as today. A similar amount of Mediterranean trees and shrubs in both areas suggest that Mediterranean woodland components were patchily distributed. The woodland distribution did not follow an environmental gradient from north to south comparable to the Holocene.

Most pronounced changes in the vegetation composition and fire activity occurred during the Lateglacial and early Holocene. However, the current chronology of core 5017-1 does not allow a definite correlation of environmental changes in the Dead Sea region to major northern hemispheric climate events. Thus, I discussed three hypotheses of possible chronologies for the Lateglacial and early Holocene based on radiometric and biostratigraphic timescales.

During the early Holocene, the Dead Sea region witnessed a gradual decrease of Mediterranean woodland elements (decreasing arboreal pollen percentages), a high fire activity (high microscopic charcoal content), and greatly increased erosion rates (high *Glomus* concentrations). Natural causes, i.e. changes of climatic parameters and their consequences, are possible. However, increasing human influences in the southern Levant during the early Holocene make anthropogenic causes very probable.

It is important to deepen the investigation of rapid climate changes during the Last Glacial and Pleistocene-Holocene transition and their influences on the environment in the southern Levant. A robust chronology is essential for comparisons with other paleorecords and a convincing interpretation of vegetation changes and their relation to climate variations in the past. Hence, a refined chronology of the investigated Dead Sea core with more dates, the exclusion of rapid deposition events such as slumps, and the integration of varying sedimentation rates among different sediments would help to strengthen the implications of this study. Moreover, further analyses of rapid vegetation variations in the Dead Sea core 5017-1 are important. Variations that are evidenced by only single pollen spectra should be confirmed in the future. Therefore, further attempts to refine the chronology and an analysis of additional pollen spectra at relevant depths will be done before submitting this manuscript to a journal.

The resulting palynological record comprising the detailed analysis of pollen, microscopic charcoal, and NPPs will further contribute towards our understanding of long-term and short-term climate oscillations and their influence on the environment. New insights into the Levantine vegetation history will help to reconstruct and evaluate the regional paleoclimate, which also comprises implications for recent and future climate changes. Furthermore, the detailed knowledge of the regional vegetation and climate history will help to understand migration patterns of modern humans.

4.7 Acknowledgements

I thank the DSDDP participants for drilling, opening, and describing the Dead Sea cores. Thomas Litt, Nadine Pickarski, Chunzhu Chen, and Vera Schiebel are acknowledged for supporting the sampling. Karen Schmeling carefully conducted the pollen preparation. I thank Mordechai Stein, Ina Neugebauer, Yael Kiro, Hiroyuki Kitagawa, and Adi Torfstein for sharing their data and their expertise. I also acknowledge Thomas Litt, Chunzhu Chen, and Sophie Stolzenberger for constructive discussions and proofreading this chapter. This project is affiliated to the CRC 806 “Our way to Europe”. I thank the German Research Foundation (DFG) for funding this project.

4.8 References

Aloni, E., Eshel, A., and Waisel, Y.: The botanical conquest of the newly exposed shores of the Dead Sea, in: The Dead Sea: The Lake and Its Setting, edited by: Niemi, T. M., Ben-Avraham, Z., and Gat, J. R., Oxford University Press, New York, Oxford, 277–281, 1997.

Anderson, R. S., Homola, R. L., Davis, R. B., and Jacobson, G. L.: Fossil remains of the mycorrhizal fungal Glomus fasciculatum complex in postglacial lake sediments from Maine, Can. J. Botany, 62, 2325–2328, doi:10.1139/b84-316, 1984.

Ayalon, A., Bar-Matthews, M., Frumkin, A., and Matthews, A.: Last Glacial warm events on Mount Hermon: the southern extension of the Alpine karst range of the east Mediterranean, Quaternary Sci. Rev., 59, 43–56, doi:10.1016/j.quascirev.2012.10.047, 2013.

Barkan, E., Luz, B., and Lazar, B.: Dynamics of the carbon dioxide system in the Dead Sea, Geochim. Cosmochim. Ac., 65, 355–368, doi:10.1016/S0016-7037(00)00540-8, 2001.

Bartov, Y., Stein, M., Enzel, Y., Agnon, A., and Reches, Z.: Lake Levels and Sequence Stratigraphy of Lake Lisan, the Late Pleistocene Precursor of the Dead Sea, Quaternary Res., 57, 9–21, doi:10.1006/qres.2001.2284, 2002.

Bartov, Y., Goldstein, S. L., Stein, M., and Enzel, Y.: Catastrophic arid episodes in the Eastern Mediterranean linked with the North Atlantic Heinrich events, Geology, 31, 439–442, doi:10.1130/0091-7613(2003)031<0439:Caeite>2.0.Co;2, 2003.

Baruch, U.: The Late Holocene Vegetational History of Lake Kinneret (Sea of Galilee), Israel, Paléorient, 12, 37–48, doi:10.3406/paleo.1986.4407, 1986.

Begin, Z. B., Ehrlich, A., and Nathan, Y.: Lake Lisan: the Pleistocene precursor of the Dead Sea, Isr. Geol. Surv. Bull., 1–30, 1974.

Berger, A. and Loutre, M. F.: Insolation values for the climate of the last 10 million years, Quaternary Sci. Rev., 10, 297–317, doi:10.1016/0277-3791(91)90033-Q, 1991.

Beug, H.-J.: Leitfaden der Pollenbestimmung für Mitteleuropa und angrenzende Gebiete, Verlag Dr. Friedrich Pfeil, München, 2004.

Bond, G., Heinrich, H., Broecker, W., Labeyrie, L., Mcmanus, J., Andrews, J., Huon, S., Jantschik, R., Clasen, S., Simet, C., Tedesco, K., Klas, M., Bonani, G., and Ivy, S.: Evidence for Massive Discharges of Icebergs into the North-Atlantic Ocean during the Last Glacial Period, Nature, 360, 245–249, doi:10.1038/360245a0, 1992.

Bottema, S.: The Younger Dryas in the Eastern Mediterranean, Quaternary Sci. Rev., 14, 883–891, doi:10.1016/0277-3791(95)00069-0, 1995.

Cheddadi, R. and Rossignol-Strick, M.: Eastern Mediterranean Quaternary paleoclimates from pollen and isotope records of marine cores in the Nile Cone Area, Paleoceanography, 10, 291–300, doi:10.1029/94PA02672, 1995.

Cheddadi, R. and Khater, C.: Climate change since the last glacial period in Lebanon and the persistence of Mediterranean species, Quaternary Sci. Rev., 150, 146–157, doi:10.1016/j.quascirev.2016.08.010, 2016.

Daniau, A. L., Sánchez-Goñi, M. F., Beaufort, L., Laggoun-Défarge, F., Loutre, M. F., and Duprat, J.: Dansgaard–Oeschger climatic variability revealed by fire emissions in southwestern Iberia, Quaternary Sci. Rev., 26, 1369–1383, doi:10.1016/j.quascirev.2007.02.005, 2007.

Daniau, A. L., Harrison, S. P., and Bartlein, P. J.: Fire regimes during the Last Glacial, Quaternary Sci. Rev., 29, 2918–2930, doi:10.1016/j.quascirev.2009.11.008, 2010.

Danin, A. and Plitmann, U.: Revision of the plant geographical territories of Israel and Sinai, Pl. Syst. Evol., 156, 43–53, doi:10.1007/BF00937200, 1987.

Danin, A.: Flora and vegetation of Israel and adjacent areas, Bocconea, 3, 18–42, 1992.

Danin, A.: Desert rocks as plant refugia in the Near East, Bot. Rev., 65, 93–170, doi:10.1007/BF02857625, 1999.

Dayan, U. and Morin, E.: Flash flood–producing rainstorms over the Dead Sea: A review, in: New frontiers in Dead Sea paleoenvironmental research, edited by: Enzel, Y., Agnon, A., and Stein, M., Geological Society of America, Boulder, 53–62, 2006.

Develle, A. L., Gasse, F., Vidal, L., Williamson, D., Demory, F., Van Campo, E., Ghaleb, B., and Thouveny, N.: A 250 ka sedimentary record from a small karstic lake in the Northern Levant (Yammoûneh, Lebanon): Paleoclimatic implications, Palaeogeogr. Palaeocl., 305, 10–27, doi:10.1016/j.palaeo.2011.02.008, 2011.

El-Moslimany, A. P.: Ecological significance of common nonarboreal pollen: examples from drylands of the Middle East, Rev. Palaeobot. Palyno., 64, 343–350, doi:10.1016/0034-6667(90)90150-H, 1990.

Enzel, Y., Bookman, R., Sharon, D., Gvirtzman, H., Dayan, U., Ziv, B., and Stein, M.: Late Holocene climates of the Near East deduced from Dead Sea level variations and modern regional winter rainfall, Quaternary Res., 60, 263–273, doi:10.1016/j.yqres.2003.07.011, 2003.

Enzel, Y., Amit, R., Dayan, U., Crouvi, O., Kahana, R., Ziv, B., and Sharon, D.: The climatic and physiographic controls of the eastern Mediterranean over the late Pleistocene climates in the southern Levant and its neighboring deserts, Global Planet. Change, 60, 165–192, doi:10.1016/j.gloplacha.2007.02.003, 2008.

Faegri, K. and Iversen, J.: Textbook of Pollen Analysis, 4 Edn., John Wiley &. Sons, Chichester, New York, Brisbane, Toronto, Singapore, 1989.

Fleitmann, D., Cheng, H., Badertscher, S., Edwards, R. L., Mudelsee, M., Göktürk, O. M., Fankhauser, A., Pickering, R., Raible, C. C., Matter, A., Kramers, J., and Tüysüz, O.: Timing and climatic impact of Greenland interstadials recorded in stalagmites from northern Turkey, Geophys. Res. Lett., 36, L19707, doi:10.1029/2009gl040050, 2009.

Garfunkel, Z.: Internal structure of the Dead Sea leaky transform (rift) in relation to plate kinematics, Tectonophysics, 80, 81–108, doi:10.1016/0040-1951(81)90143-8, 1981.

Garfunkel, Z.: The History and Formation of the Dead Sea Basin, in: The Dead Sea: The Lake and Its Setting, edited by: Niemi, T. M., Ben-Avraham, Z., and Gat, J. R., Oxford University Press, New York, Oxford, 36–56, 1997.

Gasse, F., Vidal, L., Develle, A. L., and Van Campo, E.: Hydrological variability in the Northern Levant: a 250 ka multiproxy record from the Yammoûneh (Lebanon) sedimentary sequence, Clim. Past, 7, 1261–1284, doi:10.5194/cp-7-1261-2011, 2011.

Gasse, F., Vidal, L., Van Campo, E., Demory, F., Develle, A.-L., Tachikawa, K., Elias, A., Bard, E., Garcia, M., Sonzogni, C., and Thouveny, N.: Hydroclimatic changes in northern Levant over the past 400,000 years, Quaternary Sci. Rev., 111, 1–8, doi:10.1016/j.quascirev.2014.12.019, 2015.

Gavrieli, I. and Stein, M.: On the origin and fate of the brines in the Dead Sea basin, in: New frontiers in Dead Sea paleoenvironmental research, edited by: Enzel, Y., Agnon, A., and Stein, M., Geological Society of America, Boulder, 183–194, 2006.

Goldreich, Y.: The climate of Israel: observation, research and application, Springer, New York, 2003.

Goring-Morris, N. and Belfer-Cohen, A.: The articulation of cultural processes and Late Quaternary environmental changes in Cisjordan, Paléorient, 23, 71–93, doi:10.3406/paleo.1997.4653, 1998.

Greenbaum, N., Ben-Zvi, A., Haviv, I., and Enzel, Y.: The hydrology and paleohydrology of the Dead Sea tributaries, in: New frontiers in Dead Sea paleoenvironmental research, edited by: Enzel, Y., Agnon, A., and Stein, M., Geological Society of America, Boulder, 63–93, 2006.

Grimm, E. C.: CONISS: a FORTRAN 77 program for stratigraphically constrained cluster analysis by the method of incremental sum of squares, Comput. Geosci., 13, 13–35, doi:10.1016/0098-3004(87)90022-7, 1987.

Hazan, N., Stein, M., Agnon, A., Marco, S., Nadel, D., Negendank, J. F. W., Schwab, M. J., and Neev, D.: The late Quaternary limnological history of Lake Kinneret (Sea of Galilee), Israel, Quaternary Res., 63, 60–77, doi:10.1016/j.yqres.2004.09.004, 2005.

Heinrich, H.: Origin and consequences of cyclic ice rafting in the Northeast Atlantic Ocean during the past 130,000 years, Quaternary Res., 29, 142–152, doi:10.1016/0033-5894(88)90057-9, 1988.

Hemming, S. R.: Heinrich events: Massive late Pleistocene detritus layers of the North Atlantic and their global climate imprint, Rev. Geophys., 42, RG1005, doi:10.1029/2003rg000128, 2004.

Hershkovitz, I., Marder, O., Ayalon, A., Bar-Matthews, M., Yasur, G., Boaretto, E., Caracuta, V., Alex, B., Frumkin, A., Goder-Goldberger, M., Gunz, P., Holloway, R. L., Latimer, B., Lavi, R., Matthews, A., Slon, V., Mayer, D. B.-Y., Berna, F., Bar-Oz, G., Yeshurun, R., May, H., Hans, M. G., Weber, G. W., and Barzilai, O.: Levantine cranium from Manot Cave (Israel) foreshadows the first European modern humans, Nature, 520, 216–219, doi:10.1038/nature14134, 2015.

Horowitz, A.: The Quarternary of Israel, Academic Press, New York, London, 1979.

Horowitz, A.: Palynology of arid lands, Elsevier, Amsterdam, 1992.

Kadmon, R. and Danin, A.: Distribution of plant species in Israel in relation to spatial variation in rainfall, J. Veg. Sci., 10, 421–432, doi:10.2307/3237071, 1999.

Katz, A., Kolodny, Y., and Nissenbaum, A.: The geochemical evolution of the Pleistocene Lake Lisan-Dead Sea system, Geochim. Cosmochim. Ac., 41, 1609–1626, doi:10.1016/0016-7037(77)90172-7, 1977.

Kotthoff, U., Müller, U. C., Pross, J., Schmiedl, G., Lawson, I. T., van de Schootbrugge, B., and Schulz, H.: Lateglacial and Holocene vegetation dynamics in the Aegean region: an integrated view based on pollen data from marine and terrestrial archives, Holocene, 18, 1019–1032, doi:10.1177/0959683608095573, 2008.

Kuhlwilm, M., Gronau, I., Hubisz, M. J., de Filippo, C., Prado-Martinez, J., Kircher, M., Fu, Q., Burbano, H. A., Lalueza-Fox, C., de la Rasilla, M., Rosas, A., Rudan, P., Brajkovic, D., Kucan, Ž., Gušic, I., Marques-Bonet, T., Andrés, A. M., Viola, B., Pääbo, S., Meyer, M., Siepel, A., and Castellano, S.: Ancient gene flow from early modern humans into Eastern Neanderthals, Nature, 530, 429–433, doi:10.1038/nature16544, 2016.

Kuijt, I. and Goring-Morris, N.: Foraging, Farming, and Social Complexity in the Pre-Pottery Neolithic of the Southern Levant: A Review and Synthesis, J. World Prehist., 16, 361–440, doi:10.1023/a:1022973114090, 2002.

Langgut, D., Almogi-Labin, A., Bar-Matthews, M., and Weinstein-Evron, M.: Vegetation and climate changes in the South Eastern Mediterranean during the Last Glacial-Interglacial cycle (86 ka): new marine pollen record, Quaternary Sci. Rev., 30, 3960–3972, doi:10.1016/j.quascirev.2011.10.016, 2011.

Lazar, B., Sivan, O., Yechieli, Y., Levy, E. J., Antler, G., Gavrieli, I., and Stein, M.: Long-term freshening of the Dead Sea brine revealed by porewater Cl^- and $\delta^{18}O$ in ICDP Dead Sea deep-drill, Earth Planet. Sc. Lett., 400, 94–101, doi:10.1016/j.epsl.2014.03.019, 2014.

Lelieveld, J., Hadjinicolaou, P., Kostopoulou, E., Chenoweth, J., El Maayar, M., Giannakopoulos, C., Hannides, C., Lange, M. A., Tanarhte, M., Tyrlis, E., and Xoplaki, E.: Climate change and impacts in the Eastern Mediterranean and the Middle East, Climatic Change, 114, 667–687, doi:10.1007/s10584-012-0418-4, 2012.

Litt, T.: Das Quartär als chronostratigraphische Einheit, Quaternary Science Journal, 56, 3–6, 2007.

Litt, T., Krastel, S., Sturm, M., Kipfer, R., Örcen, S., Heumann, G., Franz, S. O., Ülgen, U. B., and Niessen, F.: 'PALEOVAN', International Continental Scientific Drilling Program (ICDP): site survey results and perspectives, Quaternary Sci. Rev., 28, 1555–1567, doi:10.1016/j.quascirev.2009.03.002, 2009.

Litt, T., Ohlwein, C., Neumann, F. H., Hense, A., and Stein, M.: Holocene climate variability in the Levant from the Dead Sea pollen record, Quaternary Sci. Rev., 49, 95–105, doi:10.1016/j.quascirev.2012.06.012, 2012.

Liu, T., Broecker, W. S., and Stein, M.: Rock varnish evidence for a Younger Dryas wet period in the Dead Sea basin, Geophys. Res. Lett., 40, 2229–2235, doi:10.1002/grl.50492, 2013.

Machlus, M., Enzel, Y., Goldstein, S. L., Marco, S., and Stein, M.: Reconstructing low levels of Lake Lisan by correlating fan-delta and lacustrine deposits, Quatern. Int., 73–74, 137–144, doi:10.1016/S1040-6182(00)00070-7, 2000.

Marinova, E. and Atanassova, J.: Anthropogenic impact on vegetation and environment during the Bronze Age in the area of Lake Durankulak, NE Bulgaria: Pollen, microscopic charcoal, non-pollen palynomorphs and plant macrofossils, Rev. Palaeobot. Palyno., 141, 165–178, doi:10.1016/j.revpalbo.2006.03.011, 2006.

Masson-Delmotte, V., M. Schulz, Abe-Ouchi, A., Beer, A. G., J. , González Rouco, J. F., Jansen, E., Lambeck, K., Luterbacher, J., Naish, T., Osborn, T., Otto-Bliesner, B., Quinn, T., Ramesh, R., Rojas, M., Shao, X., and Timmermann, A.: Information from Paleoclimate Archives, in: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, edited by: Stocker, T. F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S. K., Boschung, J., Nauels, A., Xia, Y., Bex, V., and Midgley, P. M., Cambridge University Press, Cambridge, New York, 383–464, 2013.

Meadows, J.: The Younger Dryas episode and the radiocarbon chronologies of the Lake Huleh and Ghab Valley pollen diagrams, Israel and Syria, Holocene, 15, 631–636, doi:10.1191/0959683605hl838fa, 2005.

Mellars, P.: Palaeoanthropology: The earliest modern humans in Europe, Nature, 479, 483–485, doi:10.1038/479483a, 2011.

Miebach, A., Niestrath, P., Roeser, P., and Litt, T.: Impacts of climate and humans on the vegetation in northwestern Turkey: palynological insights from Lake Iznik since the Last Glacial, Clim. Past, 12, 575–593, doi:10.5194/cp-12-575-2016, 2016.

Miebach, A., Chen, C., Schwab, M. J., Stein, M., and Litt, T.: Vegetation and climate during the Last Glacial high stand (ca. 28–22 ka BP) of the Sea of Galilee, northern Israel, Quaternary Sci. Rev., submitted.

Miller, N. F.: The Near East, in: Progress in Old World Palaeoethnobotany, edited by: Zeist, v., Wasylikowa, and Behre, Balkema, Rotterdam, 133–160, 1991.

Moore, P. D., Webb, J. A., and Collinson, M. E.: Pollen analysis, 2 Edn., Blackwell Scientific Publications, Oxford, 1991.

Moritz, M. A., Krawchuk, M. A., and Pariesien, M.-A.: Pyrogeography: Understanding the ecological niche of fire, PAGES news, 18, 83–85, 2010.

Müller, U. C., Pross, J., Tzedakis, P. C., Gamble, C., and Kotthoff, U.: The role of climate in the spread of modern humans into Europe, Quaternary Sci. Rev., 30, 273–279, doi:10.1016/j.quascirev.2010.11.016, 2011.

Neugebauer, I., Brauer, A., Schwab, M. J., Waldmann, N. D., Enzel, Y., Kitagawa, H., Torfstein, A., Frank, U., Dulski, P., Agnon, A., Ariztegui, D., Ben-Avraham, Z., Goldstein, S. L., and Stein, M.: Lithology of the long sediment record recovered by the ICDP Dead Sea Deep Drilling Project (DSDDP), Quaternary Sci. Rev., 102, 149–165, doi:10.1016/j.quascirev.2014.08.013, 2014.

Neugebauer, I., Schwab, M. J., Waldmann, N. D., Tjallingii, R., Frank, U., Hadzhiivanova, E., Naumann, R., Taha, N., Agnon, A., Enzel, Y., and Brauer, A.: Hydroclimatic variability in the Levant during the early last glacial (~ 117–75 ka) derived from micro-facies analyses of deep Dead Sea sediments, Clim. Past, 12, 75–90, doi:10.5194/cp-12-75-2016, 2016.

NGRIP members: High-resolution record of Northern Hemisphere climate extending into the last interglacial period, Nature, 431, 147–151, doi:10.1038/nature02805, 2004.

Niklewski, J. and Van Zeist, W.: A Late Quaternary pollen diagram from northwestern Syria, Acta Bot. Neerl., 19, 737–754, 1970.

Oksanen, J., Blanchet, F. G., Kindt, R., Legendre, P., Minchin, P. R., O'Hara, R. B., Simpson, G. L., Solymos, P., Stevens, M. H. H., and Wagner, H.: vegan: Community Ecology Package. R package version 2.3-5. http://CRAN.R-project.org/package=vegan, 2016.

Oren, A.: Microbiological studies in the Dead Sea: 1892-1992, in: The Dead Sea: The Lake and Its Setting, edited by: Niemi, T. M., Ben-Avraham, Z., and Gat, J. R., Oxford University Press, New York, Oxford, 205–215, 1997.

Orland, I. J., Bar-Matthews, M., Ayalon, A., Matthews, A., Kozdon, R., Ushikubo, T., and Valley, J. W.: Seasonal resolution of Eastern Mediterranean climate change since 34 ka from a Soreq Cave speleothem, Geochim. Cosmochim. Ac., 89, 240–255, doi:10.1016/j.gca.2012.04.035, 2012.

Panagiotopoulos, K., Aufgebauer, A., Schäbitz, F., and Wagner, B.: Vegetation and climate history of the Lake Prespa region since the Lateglacial, Quatern. Int., 293, 157–169, doi:10.1016/j.quaint.2012.05.048, 2013.

Pickarski, N., Kwiecien, O., Langgut, D., and Litt, T.: Abrupt climate and vegetation variability of eastern Anatolia during the last glacial, Clim. Past, 11, 1491–1505, doi:10.5194/cp-11-1491-2015, 2015.

Ramsey, C. B.: Bayesian Analysis of Radiocarbon Dates, Radiocarbon, 51, 337–360, doi:10.1017/S0033822200033865, 2009.

Rasmussen, S. O., Bigler, M., Blockley, S. P., Blunier, T., Buchardt, S. L., Clausen, H. B., Cvijanovic, I., Dahl-Jensen, D., Johnsen, S. J., Fischer, H., Gkinis, V., Guillevic, M., Hoek, W. Z., Lowe, J.

J., Pedro, J. B., Popp, T., Seierstad, I. K., Steffensen, J. P., Svensson, A. M., Vallelonga, P., Vinther, B. M., Walker, M. J. C., Wheatley, J. J., and Winstrup, M.: A stratigraphic framework for abrupt climatic changes during the Last Glacial period based on three synchronized Greenland ice-core records: refining and extending the INTIMATE event stratigraphy, Quaternary Sci. Rev., 106, 14–28, doi:10.1016/j.quascirev.2014.09.007, 2014.

Reille, M.: Pollen et spores d'Europe et d'Afrique du Nord: supplement 1, Laboratoire de Botanique Historique et Palynologie, Marseille, 1995.

Reille, M.: Pollen et spores d'Europe et d'Afrique du Nord: supplement 2, Laboratoire de Botanique Historique et Palynologie, Marseille, 1998.

Reille, M.: Pollen et spores d'Europe et d'Afrique du Nord, 2 Edn., Laboratoire de Botanique Historique et Palynologie, Marseille, 1999.

Reimer, P. J., Bard, E., Bayliss, A., Beck, J. W., Blackwell, P. G., Ramsey, C. B., Buck, C. E., Cheng, H., Edwards, R. L., Friedrich, M., Grootes, P. M., Guilderson, T. P., Haflidason, H., Hajdas, I., Hatte, C., Heaton, T. J., Hoffmann, D. L., Hogg, A. G., Hughen, K. A., Kaiser, K. F., Kromer, B., Manning, S. W., Niu, M., Reimer, R. W., Richards, D. A., Scott, E. M., Southon, J. R., Staff, R. A., Turney, C. S. M., and van der Plicht, J.: Intcal13 and Marine13 Radiocarbon Age Calibration Curves 0-50,000 Years Cal BP, Radiocarbon, 55, 1869–1887, doi:10.2458/azu_js_rc.55.16947, 2013.

Richter, J., Hauck, T., Vogelsang, R., Widlok, T., Le Tensorer, J.-M., and Schmid, P.: “Contextual areas” of early Homo sapiens and their significance for human dispersal from Africa into Eurasia between 200 ka and 70 ka, Quatern. Int., 274, 5–24, doi:10.1016/j.quaint.2012.04.017, 2012.

Rollefson, G. O. and Köhler-Rollefson, I.: Early neolithic exploitation patterns in the Levant: Cultural impact on the environment, Popul. Environ., 13, 243–254, doi:10.1007/bf01271025, 1992.

Rossignol-Strick, M.: Sea-land correlation of pollen records in the eastern Mediterranean for the glacial-interglacial transition, Quaternary Sci. Rev., 14, 893–915, doi:10.1016/0277-3791(95)00070-4, 1995.

Schiebel, V.: Vegetation and climate history of the southern Levant during the last 30,000 years based on palynological investigation, Dissertation, Rheinische Friedrich-Wilhelms-Universität Bonn, Bonn, 104 pp., 2013.

Seierstad, I. K., Abbott, P. M., Bigler, M., Blunier, T., Bourne, A. J., Brook, E., Buchardt, S. L., Buizert, C., Clausen, H. B., Cook, E., Dahl-Jensen, D., Davies, S. M., Guillevic, M., Johnsen, S. J., Pedersen, D. S., Popp, T. J., Rasmussen, S. O., Severinghaus, J. P., Svensson, A., and Vinther, B. M.: Consistently dated records from the Greenland GRIP, GISP2 and NGRIP ice cores for the past 104 ka reveal regional millennial-scale δ18O gradients with possible Heinrich event imprint, Quaternary Sci. Rev., 106, 29–46, doi:10.1016/j.quascirev.2014.10.032, 2014.

Shea, J. J.: Transitions or turnovers? Climatically-forced extinctions of Homo sapiens and Neanderthals in the east Mediterranean Levant, Quaternary Sci. Rev., 27, 2253–2270, doi:10.1016/j.quascirev.2008.08.015, 2008.

Shea, J. J.: Stone Tools in the Paleolithic and Neolithic Near East: A Guide, Cambridge University Press, New York, 2013.

Shumilovskikh, L. S., Tarasov, P., Arz, H. W., Fleitmann, D., Marret, F., Nowaczyk, N., Plessen, B., Schlütz, F., and Behling, H.: Vegetation and environmental dynamics in the southern Black Sea region since 18 kyr BP derived from the marine core 22-GC3, Palaeogeogr. Palaeocl., 337–338, 177–193, doi:10.1016/j.palaeo.2012.04.015, 2012.

Shumilovskikh, L. S., Seeliger, M., Feuser, S., Novenko, E., Schlütz, F., Pint, A., Pirson, F., and Brückner, H.: The harbour of Elaia: A palynological archive for human environmental interactions during the last 7500 years, Quaternary Sci. Rev., 149, 167–187, doi:10.1016/j.quascirev.2016.07.014, 2016.

Stein, M., Starinsky, A., Katz, A., Goldstein, S. L., Machlus, M., and Schramm, A.: Strontium isotopic, chemical, and sedimentological evidence for the evolution of Lake Lisan and the Dead Sea, Geochim. Cosmochim. Ac., 61, 3975–3992, doi:10.1016/S0016-7037(97)00191-9, 1997.

Stein, M.: The sedimentary and geochemical record of Neogene-Quaternary water bodies in the Dead Sea Basin - inferences for the regional paleoclimatic history, J. Paleolimnol., 26, 271–282, doi:10.1023/A:1017529228186, 2001.

Stein, M., Torfstein, A., Gavrieli, I., and Yechieli, Y.: Abrupt aridities and salt deposition in the post-glacial Dead Sea and their North Atlantic connection, Quaternary Sci. Rev., 29, 567–575, doi:10.1016/j.quascirev.2009.10.015, 2010.

Stein, M., Ben-Avraham, Z., Goldstein, S., Agnon, A., Ariztegui, D., Brauer, A., Haug, G., Ito, E., and Yasuda, Y.: Deep drilling at the Dead Sea, Scientific Drilling, 11, 46–47, doi:10.2204/iodp.sd.11.04.2011, 2011a.

Stein, M., Ben-Avraham, Z., and Goldstein, S. L.: Dead Sea Deep Cores: A Window Into Past Climate and Seismicity, Eos, 92, 453, doi:10.1029/eost2011EO49, 2011b.

Stein, M.: The Evolution of Neogene-Quaternary Water- Bodies in the Dead Sea Rift Valley, in: Dead Sea Transform Fault System: Reviews, edited by: Garfunkel, Z., Ben-Avraham, Z., and Kagan, E., Modern Approaches in Solid Earth Sciences, Springer, Dordrecht, 279–316, 2014.

Stockhecke, M., Timmermann, A., Kipfer, R., Haug, G. H., Kwiecien, O., Friedrich, T., Menviel, L., Litt, T., Pickarski, N., and Anselmetti, F. S.: Millennial to orbital-scale variations of drought intensity in the Eastern Mediterranean, Quaternary Sci. Rev., 133, 77–95, doi:10.1016/j.quascirev.2015.12.016, 2016.

Stockmarr, J.: Tablets with spores used in absolute pollen analysis, Pollen et Spores, 13, 615–621, 1971.

Swain, A. M.: A history of fire and vegetation in northeastern Minnesota as recorded in lake sediments, Quaternary Res., 3, 383–396, doi:10.1016/0033-5894(73)90004-5, 1973.

Torfstein, A., Goldstein, S. L., Kagan, E. J., and Stein, M.: Integrated multi-site U–Th chronology of the last glacial Lake Lisan, Geochim. Cosmochim. Ac., 104, 210–231, doi:10.1016/j.gca.2012.11.003, 2013a.

Torfstein, A., Goldstein, S. L., Stein, M., and Enzel, Y.: Impacts of abrupt climate changes in the Levant from Last Glacial Dead Sea levels, Quaternary Sci. Rev., 69, 1–7, doi:10.1016/j.quascirev.2013.02.015, 2013b.

Torfstein, A., Goldstein, S. L., Kushnir, Y., Enzel, Y., Haug, G., and Stein, M.: Dead Sea drawdown and monsoonal impacts in the Levant during the last interglacial, Earth Planet. Sc. Lett., 412, 235–244, doi:10.1016/j.epsl.2014.12.013, 2015.

Turner, R., Roberts, N., Eastwood, W. J., Jenkins, E., and Rosen, A.: Fire, climate and the origins of agriculture: micro-charcoal records of biomass burning during the last glacial–interglacial transition in Southwest Asia, J. Quaternary Sci., 25, 371–386, doi:10.1002/jqs.1332, 2010.

Vaks, A., Bar-Matthews, M., Ayalon, A., Schilman, B., Gilmour, M., Hawkesworth, C. J., Frumkin, A., Kaufman, A., and Matthews, A.: Paleoclimate reconstruction based on the timing of speleothem growth and oxygen and carbon isotope composition in a cave located in the rain shadow in Israel, Quaternary Res., 59, 182–193, doi:10.1016/S0033-5894(03)00013-9, 2003.

Vaks, A., Bar-Matthews, M., Ayalon, A., Matthews, A., Frumkin, A., Dayan, U., Halicz, L., Almogi-Labin, A., and Schilman, B.: Paleoclimate and location of the border between Mediterranean climate region and the Saharo–Arabian Desert as revealed by speleothems from the northern Negev Desert, Israel, Earth Planet. Sc. Lett., 249, 384–399, doi:10.1016/j.epsl.2006.07.009, 2006.

van Zeist, W., Woldring, H., and Stapert, D.: Late Quaternary vegetation and climate of southwestern Turkey, Palaeohistoria, 17, 55–143, 1975.

van Zeist, W., Baruch, U., and Bottema, S.: Holocene palaeoecology of the Hula area, northeastern Israel, in: A timeless vale. Archaeological and related essays on the Jordan Valley in honour of Gerrit van der Kooij on the occasion of his sixty-fifth birthday, edited by: Kaptijnand, E. and Petit, L. P., Archaeological Studies Leiden University, Leiden University Press, Leiden, 29–64, 2009.

Vannière, B., Power, M. J., Roberts, N., Tinner, W., Carrión, J., Magny, M., Bartlein, P., Colombaroli, D., Daniau, A. L., Finsinger, W., Gil-Romera, G., Kaltenrieder, P., Pini, R., Sadori, L., Turner, R., Valsecchi, V., and Vescovi, E.: Circum-Mediterranean fire activity and climate changes during the mid-Holocene environmental transition (8500-2500 cal. BP), Holocene, 21, 53–73, doi:10.1177/0959683610384164, 2011.

Weinstein-Evron, M.: The paleoecology of the early Wurm in the Hula basin, Israel, Paléorient, 9, 5–19, doi:10.3406/paleo.1983.4328, 1983.

Weinstein-Evron, M., Vogel, J., and Kronfeld, J.: Further attempts at dating the palynological sequence of the Hula Lo7 core, upper Jordan Valley, Israel, Radiocarbon, 43, 561–570, doi:10.1017/S0033822200041217, 2001.

Whitlock, C. and Larsen, C.: Charcoal as a Fire Proxy, in: Tracking Environmental Change Using Lake Sediments. Volume 3: Terrestrial, Algal, and Siliceous Indicators, edited by: Smol, J. P., Birks, H. J. B., Last, W. M., Bradley, R. S., and Alverson, K., Kluwer Academic Publishers, Dordrecht, 75–97, 2001.

Whitlock, C., Higuera, P. E., McWethy, D. B., and Briles, C. E.: Paleoecological perspectives on fire ecology: revisiting the fire-regime concept, Open Ecol. J., 3, 6–23, doi:10.2174/1874213001003020006, 2010.

Yasuda, Y., Kitagawa, H., and Nakagawa, T.: The earliest record of major anthropogenic deforestation in the Ghab Valley, northwest Syria: a palynological study, Quatern. Int., 73–74, 127–136, doi:10.1016/S1040-6182(00)00069-0, 2000.

Zohary, M.: Plant Life of Palestine: Israel and Jordan, The Ronald Press Company, New York, 1962.

Zohary, M.: Vegetation of Israel and Adjacent Areas, Beihefte zum Tübinger Atlas des Vorderen Orients, Dr. Ludwig Reichert, Wiesbaden, 1982.

5 Synthesis

The main aim of this doctoral thesis was to investigate climate- and human-induced vegetation changes in northwestern Turkey and the southern Levant since the Last Glacial. Both regions are crucial to investigate because they are key regions for the history of modern humankind. The southern Levant comprise a large archaeological record suggesting different occupation periods of anatomically modern humans and Neanderthals (Shea, 2008). Northwestern Turkey displays a bottleneck region for migration processes between the Near East and Europe (Richter et al., 2012). Both regions are sensitive to detect climatic changes because they are transition areas of different climate and vegetation zones (Zohary, 1973). Thus, it was expected that already weak climate variations resulted in shifts of vegetation boundaries and alterations of pollen assemblages. To fulfill the objectives of this doctoral thesis, palynological studies at three lacustrine archives were conducted.

Sediment cores drilled at the largest lake in the Marmara region, Lake Iznik, were studied to reconstruct the regional vegetation in northwestern Turkey (chapter 2). According to Roeser et al. (2016), the sediment profile of 18 m encompasses the past ca. 31 ka BP (kilo years before present; all radiocarbon dates in this chapter have been calibrated). Pollen and selected non-pollen palynomorphs (NPPs) such as green algae and dinoflagellates were investigated.

To reveal the vegetation history in the southern Levant during marine isotope stage (MIS) 2, a sediment core recovered from the modern shore of the Sea of Galilee (Lake Kinneret) in northern Israel was analyzed. The 9 m core comprises a continuous sediment profile between ca. 28 and 22 ka BP (chapter 3), when the Sea of Galilee underwent a major lake level high stand culminating in the mergence with Lake Lisan, the Last Glacial precursor of the Dead Sea (Bartov et al., 2003; Hazan et al., 2005; Torfstein et al., 2013b). We refined the chronology with the help of new radiocarbon dates, and presented a refined lithology. We studied the pollen composition and selected NPPs in high-resolution to gain new and detailed information about the paleoenvironmental conditions during the high stand.

In addition, I analyzed the palynological assemblage of Lake Lisan sediments and early Holocene Dead Sea sediments (chapter 4) originating from a 455 m core that was drilled at the center of the Dead Sea (Neugebauer et al., 2014). The investigated sediment sequence covers 136 m and corresponds to the period of ca. 88–9 ka BP (Neugebauer et al., 2014; Torfstein et al., 2015). The study provides pollen data revealing the regional vegetation history, other palynomorph data such as freshwater and erosion indicators, and microscopic charcoal data to reconstruct the fire activity.

In the following sections, the main conclusions of the three palynological instigations are summarized and synthesized by applying to the main objectives of this doctoral thesis.

5.1 Kind and magnitude of long-term environmental changes in northwestern Turkey and the southern Levant since the Last Glacial

The Pleistocene-Holocene boundary marks the strongest climatic change, namely a pronounced northern hemispheric warming (Walker et al., 2009), during the investigated period (88–0 ka BP). Therefore, strong shifts in the investigated pollen assemblages mirroring pronounced vegetation changes were expected during this time. Furthermore, there were additional long-term climate variations during the Last Glacial and Holocene as illustrated for instance in marine isotope records (e.g., Lisiecki and Raymo, 2005) and insolation curves (e.g., Berger, 1978). These long-term climate variations might have also influenced the paleovegetation in northwestern Turkey and the southern Levant.

The palynological study inferred from Lake Iznik sediments (chapter 2) reveals strong long-term changes of the vegetation and climate in northwestern Turkey. A steppe with dwarf-shrubs, grasses, and other herbs dominated during stadials indicating dry and cold climatic conditions. Extremely low pollen concentrations and influx rates (pollen accumulation) suggest a very sparse vegetation cover and very harsh climatic conditions during MIS 2 (Fig. 5.1b). The landscape changed considerably during the Lateglacial and particularly during the Holocene. Deciduous oaks (*Quercus*) spread rapidly reflecting a warmer and moister climate. They were successively accompanied by other deciduous, coniferous, and evergreen trees.

The general trend from predominantly steppe vegetation during the Last Glacial towards forest expansion during the Holocene coincides with many previous vegetation studies from the northeastern Mediterranean region (e.g., Kotthoff et al., 2008; Müller et al., 2011; Shumilovskikh et al., 2012). However, the timing of forest expansion and amplitudes of forest density vary between the records. The Marmara region belongs to the places with one of the earliest and strongest forest expansion.

Pollen data presented in chapter 3 indicate a dominance of Irano-Turanian steppe vegetation with some stands of oak woodland in the catchment of the Sea of Galilee during MIS 2. The comparison with Holocene pollen assemblages of the Sea of Galilee reveals major differences especially during the middle and late Holocene when arboreal and frost-sensitive taxa were much more abundant (Baruch, 1986; Schiebel, 2013; Langgut et al., 2015; Fig. 5.1c). The pollen data suggest that MIS 2 was cooler, and less water was available for plants (effective moisture) compared to the middle and late Holocene.

A similar trend from steppic vegetation during MIS 2 towards increased woodland density during the Holocene was described in other Levantine palynological studies, namely from Yammouneh, Lebanon (Gasse et al., 2011, 2015), Birkat Ram, northeastern Israel (Schiebel, 2013), and marine cores from the southern Levantine Basin (Cheddadi and Rossignol-Strick, 1995; Langgut et al., 2011). However, this result disagrees with a vegetation model for northern Israel based on available pollen data from Hula Basin (Horowitz, 1992 and references therein; note that the validity of chronologies from Hula Basin are under debate (e.g., Weinstein-Evron et al., 2001; Meadows, 2005; van Zeist et al., 2009)). The general vegetation trend between MIS 2 and the Holocene inferred from Sea of Galilee sediments also coincides with northeastern Mediterranean pollen records such as the Lake Iznik record (chapter 2). The magnitude of changes in the vegetation and climate were stronger in northwestern Turkey than in northern Israel though. Further investigations are needed to fill the gap between the MIS 2 and Holocene pollen records from the Sea of Galilee and to evaluate environmental changes at the Pleistocene-Holocene boundary.

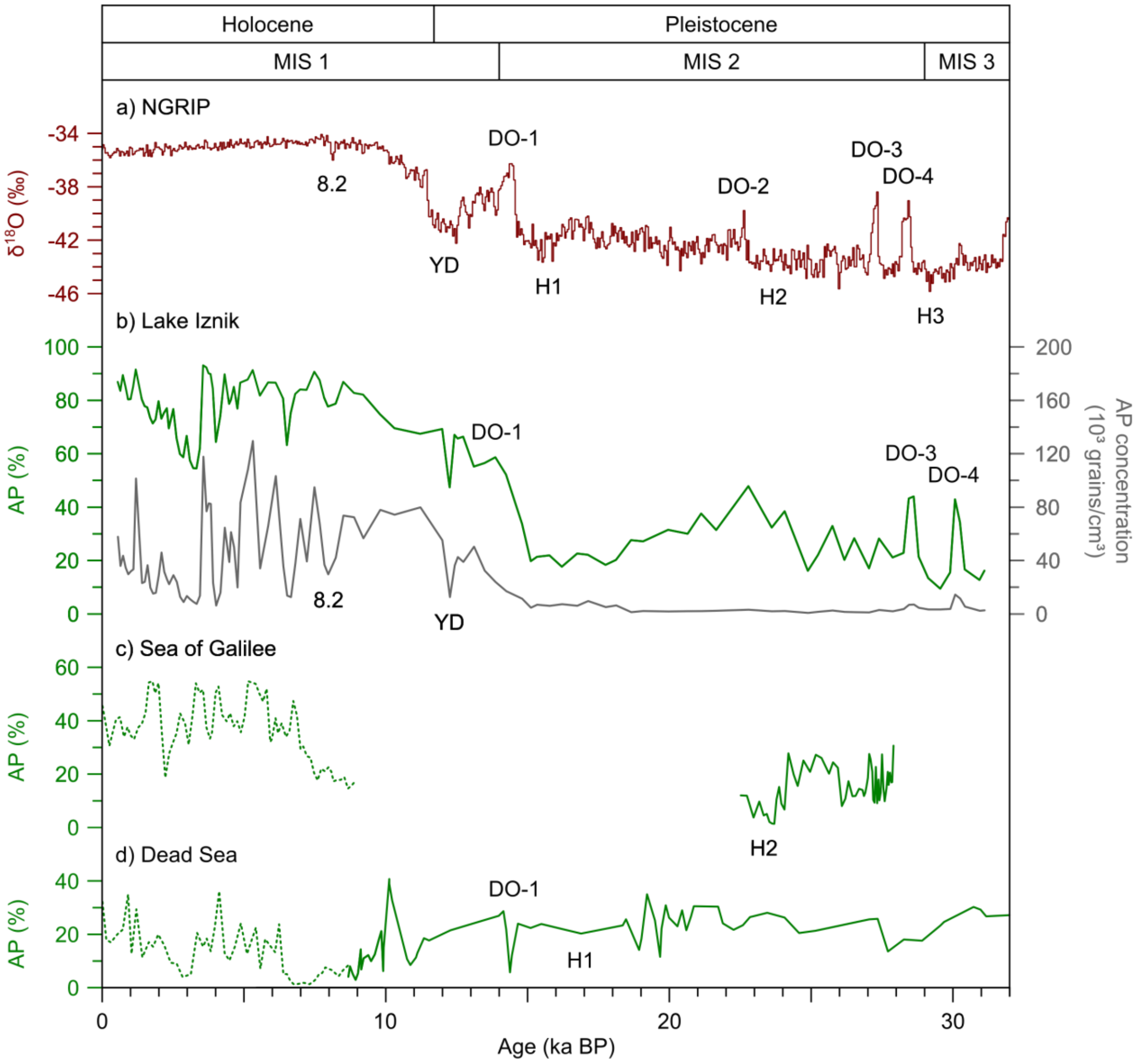


Figure 5.1: Comparison of a) Greenland δ^{18}O record (NGRIP members, 2004), b) AP (arboreal pollen) from Lake Iznik in percentages and concentrations (chapter 2), c) AP from the Sea of Galilee (chapter 3), the dashed line refers to Schiebel (2013), and d) AP from the Dead Sea (chapter 4), the dashed line refers to Litt et al. (2012). Rapid climate events are marked: DO: Dansgaard-Oeschger events, H: Heinrich events, YD: Younger Dryas, and 8.2: 8.2 ka event. Marine isotope stages (MIS) refer to Lisiecki and Raymo (2005).

In the Dead Sea region (chapter 4), further south of the Sea of Galilee, a mixture of Irano-Turanian steppe communities, Saharo-Arabian desert vegetation, and Mediterranean woodland components occurred during the Last Glacial. Pollen contributions of these three biomes slightly changed over time. During the early Last Glacial (MIS 5b/a and early MIS 4), the amount of Saharo-Arabian desert components was higher relative to later phases indicating less effective moisture. An increased proportion of Irano-Turanian steppe vegetation and Mediterranean woodland elements during the late MIS 4, MIS 3, and MIS 2 implies more effective moisture. MIS 2 was the coldest period of the investigated timeframe as indicated by a change in arboreal taxa. The Dead Sea region witnessed several changes in the ecosystem during the Lateglacial and early Holocene caused by climatic variations and/or anthropogenic influences. The timing of these events are not yet resolved by the current age-depth model. Thus, further research is needed to reveal vegetation and climate developments during the Pleistocene-Holocene transition. After these rapid and pronounced changes, a considerably different environment with sparse Mediterranean woodland, high fire activity, and strong catchment erosion prevailed in the Dead Sea region.

In contrast to other areas in the Eastern Mediterranean region such as northwestern Turkey (chapter 2) and northern Israel (chapter 3), the amount of Mediterranean woodland components in the Dead Sea catchment was averagely lower during the Holocene relative to the Last Glacial (Litt et al., 2012; chapter 4; Fig. 5.1d). This vegetation pattern was influenced by two factors: Firstly, comparatively much moisture was available for plants during the Last Glacial. Enhanced precipitation rates could have caused the increased effective moisture as suggested by Enzel et al. (2008), Stein et al. (1997), Torfstein et al. (2013b), and others. This scenario would imply a different precipitation mechanism in the Dead Sea region during the Last Glacial compared to other parts of the Eastern Mediterranean. Alternatively, reduced evaporation rates caused by low temperatures and low insolation could have resulted in more available moisture even under reduced precipitation rates (Stockhecke et al., 2016). Hence, this scenario would allow a similar precipitation mechanism in the whole Eastern Mediterranean. Secondly, the limited woodland distribution during the Holocene was influenced by anthropogenic woodland clearance. The effects of humans were particularly long-lasting in fragile, semiarid areas such as the Dead Sea region (Rollefson and Köhler-Rollefson, 1992).

5.2 Detection of rapid vegetation and climate changes in northwestern Turkey and the southern Levant during the Last Glacial and Holocene

Several rapid short-term (centennial- to millennial-scale) climate variations occurred during the Last Glacial and with lower magnitudes also during the Holocene (Mayewski et al., 2004; NGRIP members, 2004; Fig. 5.1a). In regions where the vegetation was sensitive to rapid and low magnitude climate variations, the detection of those short-term climate events is possible with the help of pollen analyses.

Dansgaard-Oeschger events

Dansgaard-Oeschger (DO) cycles were rapid climate events during the Last Glacial. They are associated with an abrupt warming followed by a gradual re-cooling (Dansgaard et al., 1982). Here, we refer to the initial rapid warming, i.e. interstadial conditions, as DO events. DO events are well documented in high-resolution Greenland ice core records (NGRIP members, 2004; Fig. 5.1a).

Vegetation changes associated with DO events are distinctively represented in the pollen record from Lake Iznik (chapter 2). The vegetation in the Marmara region became denser and more productive and shifted from steppe to forest-steppe during DO-4 and DO-3 and from steppe to woodland during DO-1 (Fig. 5.1b). An initial increase of grasses (Poaceae) followed by a spread of trees and shrubs, particularly deciduous oaks (*Quercus*) and pines (*Pinus*), indicate increased available moisture and higher temperatures. A vegetation response to DO-2 is not visible in Lake Iznik's pollen record because climatic conditions did probably not cross a critical threshold for tree growth in the Marmara region. Woodland expansion in relation to DO events, particularly to DO-1, is a common pattern in the northeastern Mediterranean region (e.g., Kotthoff et al., 2008; Müller et al., 2011; Shumilovskikh et al., 2014). However, several pollen records do not show a response to every interstadial, especially to DO-2 (e.g., Fletcher et al., 2010 and references therein). Compared to other DO events, the amplitude of the δ^{18}O curve from Greenland associated with DO-2 is in fact comparatively low (NGRIP members, 2004; Fig. 5.1a).

Changes of the climate and vegetation in northern Israel in response to DO events are not recorded in the Sea of Galilee pollen profile (chapter 3). However, this is mainly due to the investigated period. A longer pollen record could reveal a connection between vegetation changes in northern Israel and warmer condition at northern hemispheric high latitudes.

Given some chronological uncertainties in the pollen record from the Dead Sea (chapter 4), the relation between vegetation changes in the Dead Sea region and DO events as recorded in other studies is ambiguous. However, at least the onset of DO-1 is well dated. During the earliest phase of DO-1, the pollen composition was probably biased by local taxa due to an enormous lake level drop of Lake Lisan (cf. Stein et al., 2010). The lowered lake level and the consequent spread of local plants at exposed shores resulted in a statistical suppression of other taxa, in particular trees and shrubs (Fig. 5.1d). Afterwards, increased deciduous oak (*Quercus ithaburensis* type) and pistachio (*Pistacia*) pollen percentages indicate warmer conditions compared to MIS 2. The amount of deciduous oak pollen point towards persistent moist conditions in local habitats where deciduous oaks had grown. Decreased *Artemisia* percentages suggest less effective moisture relative to previous phases in open habitats possibly caused by higher temperatures (cf. NGRIP members, 2004; Ayalon et al., 2013) and a higher summer insolation (cf. Berger and Loutre, 1991). The termination of DO-1 in core 5017-1 is questionable as discussed in chapter 4. Thus, future analyses based on a refined chronology will reveal more detailed insights about DO events in the Dead Sea region.

Heinrich events

Very pronounced cold phases at northern high latitudes are associated with Heinrich events (Fig 5.1: H1–H3). Heinrich events are marked by layers of ice-rafted debris in marine cores that were caused by massive discharges of icebergs into the North Atlantic (Heinrich, 1988; Bond et al., 1992). Subsequently, the Atlantic thermohaline circulation broke down (Broecker and Hemming, 2001; Rahmstorf, 2002). Many northern hemispheric paleorecords document simultaneous climatic anomalies (e.g., Hemming, 2004).

The pollen record from Lake Iznik (chapter 2) does not indicate a clear vegetation response associated with Heinrich events. Following the explanation by Tzedakis et al. (2004), it seems that tree populations in the Marmara region were already close to their climatic tolerance limit under moderate stadial conditions. Differences between harsh Heinrich Stadials and other stadials are therefore not mirrored in the pollen assemblage. This observation is in line with other palynological studies from the northeastern Mediterranean region, e.g. from Tenaghi Philippon, Greece (Tzedakis et al., 2004) and the southern Black Sea (Shumilovskikh et al., 2014). On the contrary, Valsecchi et al. (2012) proposed harsher climatic conditions relative to earlier and later phases in the Marmara region associated with H1 based on increased pollen percentages of steppic plants and decreased percentages of temperate trees.

Several previous studies suggested strong environmental changes in the southern Levant linked to North Atlantic Heinrich events. Langgut et al. (2011) identified cold and dry phases indicated by low arboreal pollen percentages and high amounts of steppe elements corresponding to H2–H6. Other studies (e.g., Bartov et al., 2003; Hazan et al., 2005; Torfstein et al., 2013b) found a connection between the timing of Heinrich events in the North Atlantic and the timing of rapid lake level drops of Lake Lisan and the Sea of Galilee. Bartov et al. (2003) proposed that the addition of freshwater to the North Atlantic resulted in a decline of Mediterranean sea-surface temperatures (SSTs). Declined SSTs caused a reduction in the frequency and strength of storms that delivered moisture to the southern Levant. As a result, lake levels in the southern Levant abruptly dropped.

The lake level drop of the Sea of Galilee at ca. 24 ka BP was correlated to H2 (Bartov et al., 2003; Hazan et al., 2005). The pollen record from the Sea of Galilee (chapter 3) reveals strong changes in the vegetation during this time (Fig. 5.1c). Arid adapted herbaceous plants expanded and Mediterranean woodland components were considerably reduced. Thus, the pollen assemblage agrees on a reduction of effective moisture in northern Israel by the time of H2 as suggested by previous studies (e.g., Bartov et al., 2003; Lev et al., 2014).

Lake level declines of Lake Lisan associated with Heinrich events went along with depositions of gypsum units, which were identified in stratigraphic sections along the Dead Sea Basin (Bartov et al., 2003; Torfstein et al., 2013a). The gypsum unit corresponding to H1 was later correlated to the Dead Sea core 5017-1 (Neugebauer et al., 2014). A pollen sample that was taken from this gypsum unit (chapter 4) displays a sharp decline of the pollen concentration. However, this is not primary a signal of reduced pollen productivity and vegetation density. Instead, the low pollen concentration is caused by higher sedimentation rates of gypsum (cf. Stein, 2001). No significant changes in pollen percentages are visible (Fig. 5.1d). Therefore, the pollen analysis do not support a pronounced environmental change in the Dead Sea region at the time of H1. Additional pollen samples will be analyzed to confirm this result.

Younger Dryas

The Younger Dryas (YD) was the last pronounced cold period of the Pleistocene just before the onset of the warm Holocene. It is well documented in a number of paleorecords (e.g., Bottema, 1995; Litt et al., 2001; Rasmussen et al., 2014).

The YD is well identifiable in the pollen record from Lake Iznik (chapter 2). An abrupt reduction of arboreal pollen and pollen concentrations (Fig. 5.1b) indicate dryer and cooler climatic conditions in northwestern Turkey. The phase appears shorter compared to the well-dated NGRIP isotope record (Fig. 5.1a) because the current age-depth model for Lake Iznik's sediment profile does not account for lower sedimentation rates during the YD. The retreat of mesic forests and the spread of steppic vegetation are typical expressions of the YD in northwestern Turkey (Mudie et al., 2002; Valsecchi et al., 2012) and generally in the northeastern Mediterranean region (e.g., Bottema, 1995; Kotthoff et al., 2008).

The expression of the YD in the Levant is less clear. While the analyzed core KIN2 from the Sea of Galilee (chapter 3) does not encompass this period, chronological uncertainties in core 5017-1 from the Dead Sea (chapter 4) prohibit an exact determination of the YD period. A biostratigraphic correlation based on pollen spectra to other Levantine records is difficult because previous studies suggested contrasting hydroclimatic scenarios for the YD. Those investigations suggested either dry conditions (e.g., Rossignol-Strick, 1995; Langgut et al., 2011; Orland et al., 2012) or wet conditions (e.g., Stein et al., 2010; Liu et al., 2013). Chronological uncertainties in several Levantine pollen records (e.g., Rossignol-Strick, 1995; Meadows, 2005; van Zeist et al., 2009) further complicate a convincing conclusion about the vegetation and climate in the Levant during the YD.

8.2 ka event

Climatic conditions during the Holocene were generally more stable than during the Last Glacial. Still, some rapid climate events occurred (Mayewski et al., 2004). The 8.2 ka BP cold event was the most pronounced rapid climate change at northern high latitudes during the Holocene (Johnsen et al., 2001). Phases with reduced precipitation were described in several Eastern Mediterranean records, but they often lasted longer compared to the sharp and short 8.2 ka event at northern high latitudes (e.g., Staubwasser and Weiss, 2006; Kotthoff et al., 2008; Weninger et al., 2009; Göktürk et al., 2011).

The pollen record from Lake Iznik (chapter 2) is the only one of the investigated records that encompass the time around 8.2 ka BP. The palynological results indicate a decreased forest cover (lower arboreal pollen percentages and concentrations; Fig. 5.1b). On the one hand, this might be a vegetation response linked to the 8.2 ka event indicating drier climatic conditions in northwestern Turkey. On the other hand, a synchronous occurrence of several archaeological settlements in the vicinity of Lake Iznik (Bottema et al., 2001; Gerritsen et al., 2013a, b) makes it difficult to separate between anthropogenic and climatic influences on the vegetation during this period.

5.3 Vegetation and climate gradients in the southern Levant during MIS 2

The comparison of pollen records from the Sea of Galilee (chapter 3) and the Dead Sea (chapter 4) allows an assessment on vegetation and climate gradients in the southern Levant. The Sea of Galilee is located in northern Israel, a region that is nowadays characterized by Mediterranean climate with a climax of Mediterranean woodland. The Jordan River connects the Sea of Galilee with the Dead Sea situated more than 100 km further to the south. The Dead Sea is located in a hyperarid area, where Saharo-Arabian desert vegetation prevails. The surrounding mountains are covered by Irano-Turanian steppe vegetation and Mediterranean woodland. Strong gradients in precipitations, temperatures, and the vegetation distribution occur nowadays between both lakes (Zohary, 1962).

The investigated sediment profiles from the Sea of Galilee and the Dead Sea timely overlap and represent mainly the regional vegetation between 28 and 24 ka BP (MIS 2), the time when both lakes reached maximal lake levels and temporarily even merged (Bartov et al., 2003; Hazan et al., 2005; Torfstein et al., 2013b). Enzel et al. (2008) proposed strongly increased rainfall amounts compared to today for both regions during this period. Modern vegetation studies suggested that an increase of moisture coincide with a spread of arboreal vegetation (Zohary, 1962; Kadmon and Danin, 1999). Following these assumptions, Mediterranean woodland components must have increased in the whole study area during MIS 2 relative to the Holocene.

However, the results of the pollen studies from the Sea of Galilee and the Dead Sea suggest a different vegetation pattern. Percentages of deciduous oaks (*Quercus ithaburensis* type), the main arboreal component, are similar in both records. Junipers and/or Mediterranean cypresses (*Juniperus* type) were more common in the Dead Sea region resulting in somewhat higher arboreal pollen sums. The composition of non-arboreal pollen broadly coincides, although abundances partly differ in both records. Increased percentages of sedges and grasses (Cyperaceae and Poaceae) at the Sea of Galilee indicate a higher component of local vegetation in the pollen assemblage. Higher values of the goosefoot family (Chenopodiaceae) in the Dead Sea pollen record mirror the closer proximity to arid and hyperarid regions. The comparison suggests that dwarf shrubs, grasses, and other herbs predominated the vegetation in the whole study area. There was no continuous and dense vegetation belt of the Mediterranean biome in northern Israel. Thermophilous trees were probably patchily distributed in the whole study area. The gradient of available water for plants was not as strong as today between the Sea of Galilee and the Dead Sea.

Furthermore, the pollen record from the Sea of Galilee does not support increased precipitation rates in northern Israel but suggests decreased effective moisture during MIS 2 compared to today. However, this apparent contradiction to previous studies (e.g., Enzel et al., 2008) could be related to a divergence of effective moisture available to plants and total precipitation rates. The plant cover could have been shaped by effective moisture in their habitats, while additional precipitation was stored as snow on high mountains (Robinson et al., 2006) or released as flash floods. Especially in karstic systems such as the Galilee (Horowitz, 1979), a quick drainage of rainfall is possible. Plants could probably not sufficiently use the water brought by rapid snowmelts in springs or rapid drains after flash floods.

5.4 Detection and timing of human influences on the vegetation in northwestern Turkey and the southern Levant during the Holocene

It is possible to detect anthropogenic influences on the environment in lacustrine pollen records. Signs of cereal cultivation, fruticulture, grazing, forest clearance, and others can be traced in palynological assemblages (Behre, 1990; Bottema and Woldring, 1990). Moreover, secondary impacts of human activities in the catchment of a lake such as an increased erosion (Eastwood et al., 1998) or altered fire regimes (Whitlock and Larsen, 2001; Whitlock et al., 2010) can be identified. However, there are some difficulties in recording prehistoric occupation phases in pollen records from the Near East compared to other regions, e.g. Central Europe. Most cultivated species such as cereals or olive trees already occurred naturally in the Near East. Several secondary indicator species (non-cultivated plants that benefit from anthropogenic influences) were also common in the Near East before humans started to change their environments. In addition, the sensitivity of the vegetation to minor climate variations make a separation between anthropogenic and climatic influences difficult (Behre, 1990; Bottema and Woldring, 1990).

The archaeological record of the southern Levant provides clear evidence for plant cultivation, animal domestication, pastoralism, sedentary village life, and regional population growth already during the early Holocene (Pre-Pottery Neolithic; Kuijt and Goring-Morris, 2002; Shea, 2013). Therefore, anthropogenic indications in the Dead Sea pollen record (chapter 4) might already occur during this time. Indeed, the palynological assemblage of the Dead Sea core displays possible signs of anthropogenic impacts on the environment. Firstly, decreasing arboreal pollen percentages provide evidence for a gradual decrease of Mediterranean woodland (Fig. 5.1d). Secondly, a high microscopic charcoal content suggest a high regional fire activity. And thirdly, high spore concentrations of the mycorrhizal fungus *Glomus* indicate a strong increase of erosion rates in the catchment. Natural causes, i.e. variations of climatic conditions and their consequences, cannot be ruled out. But the increasing human influences in the southern Levant during the early Holocene (Kuijt and Goring-Morris, 2002; Shea, 2013) make anthropogenic causes very probable.

In contrast, the pollen study from Lake Iznik (chapter 2) does not indicate anthropogenic influences on the vegetation in northwestern Turkey during the early Holocene. The earliest possible sign of human impacts on the vegetation in the Lake Iznik area denote a forest decline around 8 ka BP (Fig. 5.1b). The contemporaneous occurrence of several settlements close to Lake Iznik (Bottema et al., 2001; Gerritsen et al., 2013a, b) may point to human activities. However, no significant increase of anthropogenic indicator species in the pollen record and the occurrence of a rapid climate event dated to 8.2 ka BP (cf. Alley et al., 1997; see also section 5.2) make a climatic cause for the forest decline very probable. The first unambiguous evidence for human-induced vegetation changes documented in Lake Iznik’s pollen record dates to ca. 4.8 ka BP during the early Bronze Age. Olive trees and cereals were cultivated, forests were cleared, and a secondary anthropogenic macchia vegetation spread. Subsequently, phases of different land use with varying intensities of cereal cropping, fruit cultivation, tree consumption, and pastoral agriculture alternated with phases of forest regeneration. There is a strong coincidence of vegetation changes recorded in the pollen assemblage from Lake Iznik and the regional archaeological history.

5.5 Future perspectives

This doctoral thesis attempted to improve the knowledge about ecosystem-climate-human interactions in northwestern Turkey and the southern Levant during the Last Glacial and Holocene. Three palynological studies at different lakes showed the strengths of each lacustrine archive to achieve this target but also specific limitations. To trade on these strengths and to minimize the limitations, various future investigations are possible.

Lake Iznik

Our palynological study based on sediments from Lake Iznik showed the potential of analyzing long-term and short-term vegetation changes in northwestern Turkey in response to northern hemispheric climate variations and regional anthropogenic activities (chapter 2). The sediment record offers various possibilities for further investigations. For instance, high-resolution vegetation analyses at specific sediment depths with specific research questions are possible. Furthermore, an analysis of microscopic charcoal and an extended analysis of NPPs such as fungal remains might reveal additional valuable information about the paleoenvironment in the Marmara region. The study of microscopic charcoal gives insights into the history of fire activity, which is also linked to anthropogenic activities (Whitlock and Larsen, 2001; Whitlock et al., 2010; see also chapter 4). Analyzing the spores of the fungus *Glomus* may provide further evidence for catchment erosion, in particular during times of prehistoric occupation phases (Anderson et al., 1984; Marinova and Atanassova, 2006; see also chapter 4). It might therefore confirm the hypothesis that rapid fluctuations in palynomorph concentrations indicate rapid changes of Lake Iznik's sedimentation rates caused by catchment erosion since the mid-Holocene.

Sea of Galilee

The investigation of core KIN2 of the north Israeli Sea of Galilee (chapter 3) highlighted the potential of this lacustrine archive for detailed vegetation reconstructions during the Last Glacial. The comparison of various proxies from the same archive allows a direct linkage between different records. And indeed, the palynological results from core KIN2 were in good agreement with lithological changes and lake level fluctuations (cf. Hazan et al., 2005). A continuous sediment core for at least the whole Last Glacial and Holocene would be particularly valuable for reconstructing the vegetation history in the southern Levant.

Dead Sea

Core 5017-1 is the longest continuous sediment profile from the Dead Sea Basin enabling the detailed reconstruction of the southern Levantine environmental history (Neugebauer et al., 2014). Especially the detailed vegetation history of the southern Levant is still insufficient understood given the scarceness of long continuous lacustrine sediment sequences and major chronological uncertainties in many pollen records (cf. Rossignol-Strick, 1995; Weinstein-Evron et al., 2001; Meadows, 2005). A robust and independent chronology is essential to reveal the vegetation and climate history in the Dead Sea region, a region that might have witnessed a different environmental history compared to other parts of the Eastern Mediterranean and Near East. Therefore, refining the chronology of core 5017-1, especially for the Lateglacial and early Holocene, would help to strengthen the implications of the palynological study presented in chapter 4. Given a refined chronology, high-resolution palynological analyses could provide new insights into (a) vegetation dynamics in relation to climate changes and (b) the relationship between environmental developments and anthropogenic processes. For instance, the detailed investigation of environmental conditions during the time of agriculture origin would be particularly relevant. The pollen data of core 5017-1 will also be used for quantitative climate reconstructions (Stolzenberger, in prep.). Using a botanical-climatological transfer function, this method provides probabilities for certain climatic conditions in the past based on pollen data (Litt et al., 2012).

5.6 References

Alley, R. B., Mayewski, P. A., Sowers, T., Stuiver, M., Taylor, K. C., and Clark, P. U.: Holocene climatic instability: A prominent, widespread event 8200 yr ago, Geology, 25, 483–486, doi:10.1130/0091-7613(1997)025<0483:hciapw>2.3.co;2, 1997.

Anderson, R. S., Homola, R. L., Davis, R. B., and Jacobson, G. L.: Fossil remains of the mycorrhizal fungal Glomus fasciculatum complex in postglacial lake sediments from Maine, Can. J. Botany, 62, 2325–2328, doi:10.1139/b84-316, 1984.

Ayalon, A., Bar-Matthews, M., Frumkin, A., and Matthews, A.: Last Glacial warm events on Mount Hermon: the southern extension of the Alpine karst range of the east Mediterranean, Quaternary Sci. Rev., 59, 43–56, doi:10.1016/j.quascirev.2012.10.047, 2013.

Bartov, Y., Goldstein, S. L., Stein, M., and Enzel, Y.: Catastrophic arid episodes in the Eastern Mediterranean linked with the North Atlantic Heinrich events, Geology, 31, 439–442, doi:10.1130/0091-7613(2003)031<0439:Caeite>2.0.Co;2, 2003.

Baruch, U.: The Late Holocene Vegetational History of Lake Kinneret (Sea of Galilee), Israel, Paléorient, 12, 37–48, doi:10.3406/paleo.1986.4407, 1986.

Behre, K.-E.: Some reflections on anthropogenic indicators and the record of prehistoric occupation phases in pollen diagrams from the Near East, in: Man's Role in the Shaping of the Eastern Mediterranean Landscape, edited by: Bottema, S., Entjes-Nieborg, G., and van Zeist, W., Balkema, Rotterdam, 219–230, 1990.

Berger, A.: Long-term variations of daily insolation and Quaternary climate changes, J. Atmos. Sci., 35, 2362–2367, doi:10.1175/1520-0469(1978)035<2362:LTVODI>2.0.CO;2, 1978.

Berger, A. and Loutre, M. F.: Insolation values for the climate of the last 10 million years, Quaternary Sci. Rev., 10, 297–317, doi:10.1016/0277-3791(91)90033-Q, 1991.

Bond, G., Heinrich, H., Broecker, W., Labeyrie, L., Mcmanus, J., Andrews, J., Huon, S., Jantschik, R., Clasen, S., Simet, C., Tedesco, K., Klas, M., Bonani, G., and Ivy, S.: Evidence for Massive Discharges of Icebergs into the North-Atlantic Ocean during the Last Glacial Period, Nature, 360, 245–249, doi:10.1038/360245a0, 1992.

Bottema, S. and Woldring, H.: Anthropogenic indicators in pollen diagrams of the Eastern Mediterranean, in: Man's Role in the Shaping of the Eastern Mediterranean Landscape, edited by: Bottema, S., Entjes-Nieborg, G., and van Zeist, W., Balkema, Rotterdam, 231–264, 1990.

Bottema, S.: The Younger Dryas in the Eastern Mediterranean, Quaternary Sci. Rev., 14, 883–891, doi:10.1016/0277-3791(95)00069-0, 1995.

Bottema, S., Woldring, H., and Kayan, I.: The Late Quarternary Vegetation History of Western Turkey, in: The Ilipinar Excavations II, edited by: Roodenberg, J. J. and Thissen, L. C., Nederlands Instituut voor het Nabije Oosten, Leiden, 327–354, 2001.

Broecker, W. S. and Hemming, S.: Climate Swings Come into Focus, Science, 294, 2308–2309, doi:10.1126/science.1068389, 2001.

Cheddadi, R. and Rossignol-Strick, M.: Eastern Mediterranean Quaternary paleoclimates from pollen and isotope records of marine cores in the Nile Cone Area, Paleoceanography, 10, 291–300, doi:10.1029/94PA02672, 1995.

Dansgaard, W., Clausen, H. B., Gundestrup, N., Hammer, C. U., Johnsen, S. F., Kristinsdottir, P. M., and Reeh, N.: A new Greenland deep ice core, Science, 218, 1273–1277, doi:10.1126/science.218.4579.1273, 1982.

Eastwood, W. J., Roberts, N., and Lamb, H. F.: Palaeoecological and Archaeological Evidence for Human Occupance in Southwest Turkey: The Beyşehir Occupation Phase, Anatolian Studies, 48, 69–86, doi:10.2307/3643048, 1998.

Enzel, Y., Amit, R., Dayan, U., Crouvi, O., Kahana, R., Ziv, B., and Sharon, D.: The climatic and physiographic controls of the eastern Mediterranean over the late Pleistocene climates in the southern Levant and its neighboring deserts, Global Planet. Change, 60, 165–192, doi:10.1016/j.gloplacha.2007.02.003, 2008.

Fletcher, W. J., Sánchez Goñi, M. F., Allen, J. R. M., Cheddadi, R., Combourieu-Nebout, N., Huntley, B., Lawson, I., Londeix, L., Magri, D., Margari, V., Müller, U. C., Naughton, F., Novenko, E., Roucoux, K., and Tzedakis, P. C.: Millennial-scale variability during the last glacial in vegetation records from Europe, Quaternary Sci. Rev., 29, 2839–2864, doi:10.1016/j.jas.2011.05.007, 2010.

Gasse, F., Vidal, L., Develle, A. L., and Van Campo, E.: Hydrological variability in the Northern Levant: a 250 ka multiproxy record from the Yammoûneh (Lebanon) sedimentary sequence, Clim. Past, 7, 1261–1284, doi:10.5194/cp-7-1261-2011, 2011.

Gasse, F., Vidal, L., Van Campo, E., Demory, F., Develle, A.-L., Tachikawa, K., Elias, A., Bard, E., Garcia, M., Sonzogni, C., and Thouveny, N.: Hydroclimatic changes in northern Levant over the past 400,000 years, Quaternary Sci. Rev., 111, 1–8, doi:10.1016/j.quascirev.2014.12.019, 2015.

Gerritsen, F., Fokke, A., Özbal, R., and Thissen, L. C.: The Earliest Neolithic Levels at Barcin Höyük, Northwestern Turkey, Anatolica, 39, 53–92, doi:10.2143/ANA.39.0.2990784, 2013a.

Gerritsen, F., Özbal, R., Thissen, L., Özdoğan, M., Başgelen, N., and Kuniholm, P.: Barcın Höyük: the beginnings of farming in the Marmara region, in: The Neolithic in Turkey: New Excavations and New Research. Vol. 5 Northwestern Turkey and Istanbul, edited by: Özdoğan, M., Başgelen, N., and Kuniholm, P., Archaeology and Art Publications, Istanbul, 93–112, 2013b.

Göktürk, O. M., Fleitmann, D., Badertscher, S., Cheng, H., Edwards, R. L., Leuenberger, M., Fankhauser, A., Tüysüz, O., and Kramers, J.: Climate on the southern Black Sea coast during the Holocene: implications from the Sofular Cave record, Quaternary Sci. Rev., 30, 2433–2445, doi:10.1016/j.quascirev.2011.05.007, 2011.

Hazan, N., Stein, M., Agnon, A., Marco, S., Nadel, D., Negendank, J. F. W., Schwab, M. J., and Neev, D.: The late Quaternary limnological history of Lake Kinneret (Sea of Galilee), Israel, Quaternary Res., 63, 60–77, doi:10.1016/j.yqres.2004.09.004, 2005.

Heinrich, H.: Origin and consequences of cyclic ice rafting in the Northeast Atlantic Ocean during the past 130,000 years, Quaternary Res., 29, 142–152, doi:10.1016/0033-5894(88)90057-9, 1988.

Hemming, S. R.: Heinrich events: Massive late Pleistocene detritus layers of the North Atlantic and their global climate imprint, Rev. Geophys., 42, RG1005, doi:10.1029/2003rg000128, 2004.

Horowitz, A.: The Quarternary of Israel, Academic Press, New York, London, 1979.

Horowitz, A.: Palynology of arid lands, Elsevier, Amsterdam, 1992.

Johnsen, S. J., Dahl-Jensen, D., Gundestrup, N., Steffensen, J. P., Clausen, H. B., Miller, H., Masson-Delmotte, V., Sveinbjörnsdottir, A. E., and White, J.: Oxygen isotope and palaeotemperature records from six Greenland ice-core stations: Camp Century, Dye-3, GRIP, GISP2, Renland and NorthGRIP, J. Quaternary Sci., 16, 299–307, doi:10.1002/jqs.622, 2001.

Kadmon, R. and Danin, A.: Distribution of plant species in Israel in relation to spatial variation in rainfall, J. Veg. Sci., 10, 421–432, doi:10.2307/3237071, 1999.

Kotthoff, U., Müller, U. C., Pross, J., Schmiedl, G., Lawson, I. T., van de Schootbrugge, B., and Schulz, H.: Lateglacial and Holocene vegetation dynamics in the Aegean region: an integrated view based on pollen data from marine and terrestrial archives, Holocene, 18, 1019–1032, doi:10.1177/0959683608095573, 2008.

Kuijt, I. and Goring-Morris, N.: Foraging, Farming, and Social Complexity in the Pre-Pottery Neolithic of the Southern Levant: A Review and Synthesis, J. World Prehist., 16, 361–440, doi:10.1023/a:1022973114090, 2002.

Langgut, D., Almogi-Labin, A., Bar-Matthews, M., and Weinstein-Evron, M.: Vegetation and climate changes in the South Eastern Mediterranean during the Last Glacial-Interglacial cycle (86 ka): new marine pollen record, Quaternary Sci. Rev., 30, 3960–3972, doi:10.1016/j.quascirev.2011.10.016, 2011.

Langgut, D., Finkelstein, I., Litt, T., Neumann, F. H., and Stein, M.: Vegetation and Climate Changes during the Bronze and Iron Ages (~3600–600 BCE) in the Southern Levant Based on Palynological Records, Radiocarbon, 57, 217–235, doi:10.2458/azu_rc.57.18555, 2015.

Lev, L., Almogi-Labin, A., Mischke, S., Ito, E., Ben-Avraham, Z., and Stein, M.: Paleohydrology of Lake Kinneret during the Heinrich event H2, Palaeogeogr. Palaeocl., 396, 183–193, doi:10.1016/j.palaeo.2014.01.005, 2014.

Lisiecki, L. E. and Raymo, M. E.: A Pliocene-Pleistocene stack of 57 globally distributed benthic $\delta^{18}O$ records, Paleoceanography, 20, PA1003, doi:10.1029/2004PA001071, 2005.

Litt, T., Brauer, A., Goslar, T., Merkt, J., Bałaga, K., Müller, H., Ralska-Jasiewiczowa, M., Stebich, M., and Negendank, J. F. W.: Correlation and synchronisation of Lateglacial continental sequences in northern central Europe based on annually laminated lacustrine sediments, Quaternary Sci. Rev., 20, 1233–1249, doi:10.1016/S0277-3791(00)00149-9, 2001.

Litt, T., Ohlwein, C., Neumann, F. H., Hense, A., and Stein, M.: Holocene climate variability in the Levant from the Dead Sea pollen record, Quaternary Sci. Rev., 49, 95–105, doi:10.1016/j.quascirev.2012.06.012, 2012.

Liu, T., Broecker, W. S., and Stein, M.: Rock varnish evidence for a Younger Dryas wet period in the Dead Sea basin, Geophys. Res. Lett., 40, 2229–2235, doi:10.1002/grl.50492, 2013.

Marinova, E. and Atanassova, J.: Anthropogenic impact on vegetation and environment during the Bronze Age in the area of Lake Durankulak, NE Bulgaria: Pollen, microscopic charcoal, non-pollen palynomorphs and plant macrofossils, Rev. Palaeobot. Palyno., 141, 165–178, doi:10.1016/j.revpalbo.2006.03.011, 2006.

Mayewski, P. A., Rohling, E. E., Curt Stager, J., Karlén, W., Maasch, K. A., David Meeker, L., Meyerson, E. A., Gasse, F., van Kreveld, S., Holmgren, K., Lee-Thorp, J., Rosqvist, G., Rack, F., Staubwasser, M., Schneider, R. R., and Steig, E. J.: Holocene climate variability, Quaternary Res., 62, 243–255, doi:10.1016/j.yqres.2004.07.001, 2004.

Meadows, J.: The Younger Dryas episode and the radiocarbon chronologies of the Lake Huleh and Ghab Valley pollen diagrams, Israel and Syria, Holocene, 15, 631–636, doi:10.1191/0959683605hl838fa, 2005.

Mudie, P. J., Rochon, A., and Aksu, A. E.: Pollen stratigraphy of Late Quaternary cores from Marmara Sea: land-sea correlation and paleoclimatic history, Mar. Geol., 190, 233–260, doi:10.1016/S0025-3227(02)00349-3, 2002.

Müller, U. C., Pross, J., Tzedakis, P. C., Gamble, C., and Kotthoff, U.: The role of climate in the spread of modern humans into Europe, Quaternary Sci. Rev., 30, 273–279, doi:10.1016/j.quascirev.2010.11.016, 2011.

Neugebauer, I., Brauer, A., Schwab, M. J., Waldmann, N. D., Enzel, Y., Kitagawa, H., Torfstein, A., Frank, U., Dulski, P., Agnon, A., Ariztegui, D., Ben-Avraham, Z., Goldstein, S. L., and Stein, M.: Lithology of the long sediment record recovered by the ICDP Dead Sea Deep Drilling Project (DSDDP), Quaternary Sci. Rev., 102, 149–165, doi:10.1016/j.quascirev.2014.08.013, 2014.

NGRIP members: High-resolution record of Northern Hemisphere climate extending into the last interglacial period, Nature, 431, 147–151, doi:10.1038/nature02805, 2004.

Orland, I. J., Bar-Matthews, M., Ayalon, A., Matthews, A., Kozdon, R., Ushikubo, T., and Valley, J. W.: Seasonal resolution of Eastern Mediterranean climate change since 34 ka from a Soreq Cave speleothem, Geochim. Cosmochim. Ac., 89, 240–255, doi:10.1016/j.gca.2012.04.035, 2012.

Rahmstorf, S.: Ocean circulation and climate during the past 120,000 years, Nature, 419, 207–214, doi:10.1038/nature01090, 2002.

Rasmussen, S. O., Bigler, M., Blockley, S. P., Blunier, T., Buchardt, S. L., Clausen, H. B., Cvijanovic, I., Dahl-Jensen, D., Johnsen, S. J., Fischer, H., Gkinis, V., Guillevic, M., Hoek, W. Z., Lowe, J. J., Pedro, J. B., Popp, T., Seierstad, I. K., Steffensen, J. P., Svensson, A. M., Vallelonga, P., Vinther, B. M., Walker, M. J. C., Wheatley, J. J., and Winstrup, M.: A stratigraphic framework for abrupt climatic changes during the Last Glacial period based on three synchronized Greenland ice-core records: refining and extending the INTIMATE event stratigraphy, Quaternary Sci. Rev., 106, 14–28, doi:10.1016/j.quascirev.2014.09.007, 2014.

Richter, J., Melles, M., and Schäbitz, F.: Temporal and spatial corridors of Homo sapiens sapiens population dynamics during the Late Pleistocene and early Holocene, Quatern. Int., 274, 1–4, doi:10.1016/j.quaint.2012.06.009, 2012.

Robinson, S. A., Black, S., Sellwood, B. W., and Valdes, P. J.: A review of palaeoclimates and palaeoenvironments in the Levant and Eastern Mediterranean from 25,000 to 5000 years BP: setting the environmental background for the evolution of human civilisation, Quaternary Sci. Rev., 25, 1517–1541, doi:10.1016/j.quascirev.2006.02.006, 2006.

Roeser, P., Franz, S. O., and Litt, T.: Aragonite and calcite preservation in sediments from Lake Iznik related to bottom lake oxygenation and water column depth, Sedimentology, Accepted Author Manuscript, doi:10.1111/sed.12306, 2016.

Rollefson, G. O. and Köhler-Rollefson, I.: Early neolithic exploitation patterns in the Levant: Cultural impact on the environment, Popul. Environ., 13, 243–254, doi:10.1007/bf01271025, 1992.

Rossignol-Strick, M.: Sea-land correlation of pollen records in the eastern Mediterranean for the glacial-interglacial transition, Quaternary Sci. Rev., 14, 893–915, doi:10.1016/0277-3791(95)00070-4, 1995.

Schiebel, V.: Vegetation and climate history of the southern Levant during the last 30,000 years based on palynological investigation, Dissertation, Rheinische Friedrich-Wilhelms-Universität Bonn, Bonn, 104 pp., 2013.

Shea, J. J.: Transitions or turnovers? Climatically-forced extinctions of Homo sapiens and Neanderthals in the east Mediterranean Levant, Quaternary Sci. Rev., 27, 2253–2270, doi:10.1016/j.quascirev.2008.08.015, 2008.

Shea, J. J.: Stone Tools in the Paleolithic and Neolithic Near East: A Guide, Cambridge University Press, New York, 2013.

Shumilovskikh, L. S., Tarasov, P., Arz, H. W., Fleitmann, D., Marret, F., Nowaczyk, N., Plessen, B., Schlütz, F., and Behling, H.: Vegetation and environmental dynamics in the southern Black Sea region since 18 kyr BP derived from the marine core 22-GC3, Palaeogeogr. Palaeocl., 337–338, 177–193, doi:10.1016/j.palaeo.2012.04.015, 2012.

Shumilovskikh, L. S., Fleitmann, D., Nowaczyk, N. R., Behling, H., Marret, F., Wegwerth, A., and Arz, H. W.: Orbital- and millennial-scale environmental changes between 64 and 20 ka BP recorded in Black Sea sediments, Clim. Past, 10, 939–954, doi:10.5194/cp-10-939-2014, 2014.

Staubwasser, M. and Weiss, H.: Holocene climate and cultural evolution in late prehistoric–early historic West Asia, Quaternary Res., 66, 372–387, doi:10.1016/j.yqres.2006.09.001, 2006.

Stein, M., Starinsky, A., Katz, A., Goldstein, S. L., Machlus, M., and Schramm, A.: Strontium isotopic, chemical, and sedimentological evidence for the evolution of Lake Lisan and the Dead Sea, Geochim. Cosmochim. Ac., 61, 3975–3992, doi:10.1016/S0016-7037(97)00191-9, 1997.

Stein, M.: The sedimentary and geochemical record of Neogene-Quaternary water bodies in the Dead Sea Basin - inferences for the regional paleoclimatic history, J. Paleolimnol., 26, 271–282, doi:10.1023/A:1017529228186, 2001.

Stein, M., Torfstein, A., Gavrieli, I., and Yechieli, Y.: Abrupt aridities and salt deposition in the post-glacial Dead Sea and their North Atlantic connection, Quaternary Sci. Rev., 29, 567–575, doi:10.1016/j.quascirev.2009.10.015, 2010.

Stockhecke, M., Timmermann, A., Kipfer, R., Haug, G. H., Kwiecien, O., Friedrich, T., Menviel, L., Litt, T., Pickarski, N., and Anselmetti, F. S.: Millennial to orbital-scale variations of drought intensity in the Eastern Mediterranean, Quaternary Sci. Rev., 133, 77–95, doi:10.1016/j.quascirev.2015.12.016, 2016.

Torfstein, A., Goldstein, S. L., Kagan, E. J., and Stein, M.: Integrated multi-site U–Th chronology of the last glacial Lake Lisan, Geochim. Cosmochim. Ac., 104, 210–231, doi:10.1016/j.gca.2012.11.003, 2013a.

Torfstein, A., Goldstein, S. L., Stein, M., and Enzel, Y.: Impacts of abrupt climate changes in the Levant from Last Glacial Dead Sea levels, Quaternary Sci. Rev., 69, 1–7, doi:10.1016/j.quascirev.2013.02.015, 2013b.

Torfstein, A., Goldstein, S. L., Kushnir, Y., Enzel, Y., Haug, G., and Stein, M.: Dead Sea drawdown and monsoonal impacts in the Levant during the last interglacial, Earth Planet. Sc. Lett., 412, 235–244, doi:10.1016/j.epsl.2014.12.013, 2015.

Tzedakis, P. C., Frogley, M. R., Lawson, I. T., Preece, R. C., Cacho, I., and de Abreu, L.: Ecological thresholds and patterns of millennial-scale climate variability: The response of vegetation in Greece during the last glacial period, Geology, 32, 109–112, doi:10.1130/G20118.1, 2004.

Valsecchi, V., Sánchez-Goñi, M. F., and Londeix, L.: Vegetation dynamics in the Northeastern Mediterranean region during the past 23 000 yr: insights from a new pollen record from the Sea of Marmara, Clim. Past, 8, 1941–1956, doi:10.5194/cp-8-1941-2012, 2012.

van Zeist, W., Baruch, U., and Bottema, S.: Holocene palaeoecology of the Hula area, northeastern Israel, in: A timeless vale. Archaeological and related essays on the Jordan Valley in honour of Gerrit van der Kooij on the occasion of his sixty-fifth birthday, edited by: Kaptijnand, E. and Petit, L. P., Archaeological Studies Leiden University, Leiden University Press, Leiden, 29–64, 2009.

Walker, M., Johnsen, S., Rasmussen, S. O., Popp, T., Steffensen, J.-P., Gibbard, P., Hoek, W., Lowe, J., Andrews, J., Björck, S., Cwynar, L. C., Hughen, K., Kershaw, P., Kromer, B., Litt, T., Lowe, D. J., Nakagawa, T., Newnham, R., and Schwander, J.: Formal definition and dating of the GSSP (Global Stratotype Section and Point) for the base of the Holocene using the Greenland NGRIP ice core, and selected auxiliary records, J. Quaternary Sci., 24, 3–17, doi:10.1002/jqs.1227, 2009.

Weinstein-Evron, M., Vogel, J., and Kronfeld, J.: Further attempts at dating the palynological sequence of the Hula Lo7 core, upper Jordan Valley, Israel, Radiocarbon, 43, 561–570, doi:10.1017/S0033822200041217, 2001.

Weninger, B., Clare, L., Rohling, E. J., Bar-Yosef, O., Böhner, U., Budja, M., Bundschuh, M., Feurdean, A., Gebel, H.-G., and Jöris, O.: The impact of rapid climate change on prehistoric societies during the Holocene in the Eastern Mediterranean, Documenta Praehistorica, 36, 7–59, doi:10.4312/dp.36.2, 2009.

Whitlock, C. and Larsen, C.: Charcoal as a Fire Proxy, in: Tracking Environmental Change Using Lake Sediments. Volume 3: Terrestrial, Algal, and Siliceous Indicators, edited by: Smol, J. P., Birks, H. J. B., Last, W. M., Bradley, R. S., and Alverson, K., Kluwer Academic Publishers, Dordrecht, 75–97, 2001.

Whitlock, C., Higuera, P. E., McWethy, D. B., and Briles, C. E.: Paleoecological perspectives on fire ecology: revisiting the fire-regime concept, Open Ecol. J., 3, 6–23, doi:10.2174/1874213001003020006, 2010.

Zohary, M.: Plant Life of Palestine: Israel and Jordan, The Ronald Press Company, New York, 1962.

Zohary, M.: Geobotanical Foundations of the Middle East, Gustav Fischer Verlag, Stuttgart, 1973.

List of figures

List of tables

Acknowledgments

This project is affiliated to the CRC 806 “Our way to Europe” and was funded by the German Research Foundation (DFG). The study was carried out at the Steinmann Institute for Geology, Paleontology, and Mineralogy of the University of Bonn, Germany, under the supervision of Prof. Dr. Thomas Litt.

I thank my supervisor Prof. Dr. Thomas Litt for his trust and support, his helpful suggestions, and constructive discussions. I also acknowledge my second referee Prof. Dr. Dietmar Quandt for evaluating this doctoral thesis.

Furthermore, I would like to thank all recent and former members of the working group Paleobotany of the Steinmann Institute. In particular, I thank Dr. Patricia Roeser, Dr. Nadine Pickarski, Dr. Georg Heumann, Chunzhu Chen, and Hannah Vossel for productive discussions, providing help with pollen identifications, improvements of abstracts, manuscripts, and this dissertation, and a pleasant working atmosphere. I am very grateful to Karen Schmeling for preparing pollen samples. I also acknowledge Helen Böttcher and Georg Oleschinski for their technical support.

This project greatly benefited from the collaboration with colleagues. I particularly want to thank my co-authors Chunzhu Chen, Phoebe Niestrath, Dr. Patricia Roeser, Dr. Markus J. Schwab, Prof. Dr. Mordechai Stein, and Prof. Dr. Thomas Litt. Their comments and our discussions greatly improved the manuscripts. Furthermore, I like to thank all colleagues who shared their data and their expertise with me. I also thank the colleagues and friends from the CRC 806 and IRTG, particularly Sophie Stolzenberger.

I am very grateful to be supported by my family and friends. I particularly thank Karina, Thorben, and my parents.

תודה רבה! Teşekkür ederim**!** Thank you! Vielen Dank!